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Regulatory Impact Analysis, Oxides of Nitrogen Pollutant Specific Study and Summary and Analysis of Comments

(U.S.) Environmental Protection Agency
Ann Arbor, MI

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Regulatory Impact Analysis, Oxides of Nitrogen Pollutant Specific Study and Summary and Analysis of Comments

Control of Air Pollution from New Motor Vehicles and New Motor Vehicle Engines: Gaseous Emission Regulations for 1987 and Later Model Year Light-Duty Vehicles, and for 1988 and Later Model Year Light-Duty Trucks and Heavy-Duty Engines; Particulate Emission Regulations for 1988 and Later Model Year Heavy-Duty Diesel Engines

March 1985

Environmental Protection Agency
Office of Air and Radiation
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This document summarizes the results of all analyses conducted in support of the final rule for nitrogen oxide emission standards for 1987 and later model year light duty trucks and the particulate emission standards for 1988 and later model year heavy-duty diesel engines. (50 FR 10606, March 15, 1985).

The report also includes the technological feasibility, economic impact, environmental effects, cost effectiveness of the standards and the development of data on the impacts of several regulatory alternatives.

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CHAPTER 1

INTRODUCTION

I. Organization

As required by Executive Order 12291, this document has been prepared to summarize the results of all analyses conducted in support of the final rule for gaseous emission regulations for 1988 and later model year light-duty vehicles, light-duty trucks, and heavy-duty engines and for particulate emission regulations for 1988 and later model year heavy-duty diesel engines. In addition, this document also provides a summary and analysis of most of the comments received in response to the Notice of Proposed Rulemaking (49 FR 40258 October 15, 1984). Included here is a consideration of the technological feasibility, economic impact, environmental effects and cost effectiveness of the standards along with the development of data on the impacts of several regulatory alternatives. The remaining issues raised by commenters to this rulemaking are reviewed and responded to in the preamble. These include the proposed averaging program, allowable maintenance provisions and high altitude standards. The oxides of nitrogen (NOx) environmental impact analysis contained in this document also serves as the NOx pollutant-specific study required by Section 202(a)(3)(E) of the Clean Air Act.

The material presented in this document deals primarily with those areas of the draft Regulatory Impact Analysis-[1] which were the subject of public comment. Areas of analysis which were not commented upon are repeated here only where needed to aid the understanding of material being revised. The draft analysis is therefore incorporated into this document by reference for treatment of topics not specifically re-addressed herein.

II. Background of the Regulations

A. Clean Air Act Requirements

The Clean Air Act Amendments of 1977 created a statutory heavy-duty vehicle (HDV) class and established mandatory emissions reductions for that class. Under the language of the amendments, all vehicles over 6,000 lbs gross vehicle weight (GVW) were defined as "heavy duty" and were required to achieve a 75 percent reduction in NOx emissions from uncontrolled levels, effective with the 1985 model year.

The Act made no specific provisions for light-duty trucks (LDTs), which at that time only encompassed LDTs between 0 and 6,000 lbs GVW (light LDTs). These LDTs were regulated by EPA as a separate class under the general authority of the Clean Air Act. Beginning with the 1979 model year, EPA expanded its standards for the LDT class to 8,500 lbs GVW, thus encompassing those heavy LDTs (6,001 to 8,500 lbs GVW) which are subject to the heavy-duty vehicle provisions mentioned above.

The Act also authorizes the Administrator to temporarily establish revised NOx standards for heavy-duty engines if the statutory standards cannot be achieved without increasing cost or decreasing fuel economy to an "excessive and unreasonable degree."[2] The new heavy-duty engine NOx standards in this document are being promulgated under these provisions of the Act.

The amendments of 1977 also require the "greatest degree of [particulate] emissions reduction achievable," given the availability of control technology and considering cost, leadtime and energy impacts.[3] These reductions were to begin in the 1981 model year. Although not specifically limited as to applicability in the language of the Amendments of 1977, it was recognized that the requirement was aimed at diesel engines. The heavy-duty diesel engine (HDDE) particulate standards in this rulemaking are based on this authority.

B. Regulatory History

The first NOx standards antedated the amendments of 1977. Prior to the 1975 model year, LDTs complied with the 3.0 g/mi NOx standard that had been established two years earlier for LDVs. With the splitting off of the LDT class for the 1975 model year, LDTs were required to meet a NOx standard of 3.1 g/mi, comparable in stringency to the LDV standard. Heavy-duty engines (HDEs) had no separate NOx standard until the 1985 model year, however, there have been combined hydrocarbon (HC) + NOx standards in place for HDEs since the 1974 model year.

The current NOx standard for 1979 and later model year LDTs is 2.3 g/mi, comparable in stringency to the 2.0 g/mi standard established for LDVs of that year. Beginning in 1979, the LDT class was expanded to include vehicles between 6,001 and 8,500 lbs GVW. The current NOx standard for HDEs is 10.7 g/BHP-hr, established originally for the 1984 model year, but later made optional until the 1985 model year.

Turning now to more recent actions, an Advanced Notice of Proposed Rulemaking (ANPRM) was promulgated for LDT and HDE NOx emissions in January of 1981 (46 FR 5838). Standards of 1.2 grams per mile for LDTs and 4.0 g/BHP-hr for HDEs were suggested effective for the 1985 and 1986 model years, respectively. These standards did not correspond to the statutory 75 percent reduction as noted above, but were proposed because they were comparable in stringency to the existing 1.0 g/mi LDV NOx standard in the case of LDTs and because they represented what EPA believed at that time to be the lowest practicable standard given the available technology in the case of HDEs.

The first diesel particulate standards were established for LDVs and LDTs, effective beginning with the 1981 model year. A standard of 0.60 g/mi was established for both LDVs and LDTs, representing an achievable level for the (then) available technology. More stringent standards (at 0.26 for LDTs, and 0.20 for LDVs) were also promulgated effective beginning with the 1985 model year, but these have been delayed and will now be effective for the 1987 model year (49 FR 3010, January 24, 1984). For HDDEs, a Notice of Proposed Rulemaking (NPRM) was published in January, 1981 (46 FR 1910) which proposed a standard of 0.25 g/BHP-hr for 1986 and later model years.

Because of the related technical issues that were raised during the comment periods for both the NOx ANPRM and the particulate NPRM and the interrelationship between NOx and particulate emissions, EPA decided to issue a combined NPRM to address these issues to insure that manufacturers could direct their efforts at meeting a unified set of emission standards. The Notice of Proposed Rulemaking was published on October 15, 1984 (49 FR 40258). This final rule, preceeded by public hearings and a public comment period, completes the rulemaking process.

III. Description of the Action

A. New Emissions Standards

This rulemaking contains new low-altitude NOx standards for LDTs and HDEs, new low-altitude particulate standards for HDDEs and new high-altitude idle CO, NOx and particulate standards for LDTs. For 1988 and later model years, the NOx standard for LDTs is 1.2 g/mi for LDTs up to and including 3,750 lbs loaded-vehicle weight. The standard for 1988 and later model year LDTs over the above weight limit is 1.7 g/mi. A staged NOx standard is established for HDEs to allow leadtime for further development of control technology. The NOx standard for 1988-90 model year HDEs is 6.0 g/BHP-hr, representing a level that is achievable given the available leadtime for engines currently in production, with a more stringent standard of 5.0 g/BHP-hr effective for 1991 and later model year engines.

A three-phased particulate standard is established for HDDEs. Model year 1988-90 HDDEs will meet a standard of 0.60 g/BHP-hr. For 1991-93 model years, urban bus engines will comply with a standard of 0.10 g/BHP-hr, while the remaining HDDEs will meet a standard of 0.25 g/BHP-hr. Both of these 1991 standards will likely require the use of trap oxidizers on a majority of applications. This will be followed by the third phase, when all 1994 and later model year HDDEs will comply with the 0.10 g/BHP-hr standard.

Finally, certain new high altitude standards are established for light-duty trucks. NOx standards equal to the 1.2 g/mi and 1.7 g/mi low-altitude standards are established, along with an idle CO standard of 0.50 percent of exhaust gas flow at idle (gasoline-fueled light-duty trucks only) and a particulate standard of 0.26 g/mi (diesel light-duty trucks only).

B. Particulate and NOx Averaging

With this rulemaking, particulate averaging will be afforded to manufacturers of 1991 and later model year HDDEs. However, they will not be allowed to average HDDEs with LDDTs or LDDVs if the manufacturer's product line also includes these vehicle types. Similarly, averaging California engines with engines intended for sale in non-California areas will not be permitted, although averaging within each of these areas is allowed. Urban buses will be excluded from the particulate averaging program to insure the maximum reduction in urban particulate emissions. Because HDDE standards are expressed in mass per unit of work (g/BHP-hr) rather than mass per unit of distance travelled (g/mi) and because HDDEs are divided into subclasses with widely varying useful life periods, averaging will be limited to within each of the existing subclasses (light-, medium-, and heavy-heavy duty) and the calculation of average particulate emissions must include weighting factors for brake horsepower as well as for production volume.

NOx averaging has been established for 1991 and later model year HDEs and is similar to the particulate averaging program, with the following exceptions. The NOx averaging program is restricted by fuel type, with gasoline-fueled and diesel engines complying with the standard by separate averages. For HDDEs, the averaging is restricted by engine subclass (light, medium, and heavy); however, gasoline-fueled HDEs have no such restriction. Also, urban buses excluded from particulate averaging may be included in the NOx averaging program for all HDEs.

Finally, NOx averaging for light-duty trucks is established beginning in 1988. This program is patterned closely after those established for heavy-duty engines and the existing light-duty diesel averaging program. Further details for both the NOx and particulate averaging programs are outlined in the preamble and included in the revised regulations.

C. New Allowable Maintenance Regulations

The allowable maintenance provisions proposed have been retained largely unchanged. The concept of emission- and non-emission-related maintenance has been extended from LDTs and HDEs to encompass LDVs as well. Maintenance intervals have been changed, including revisions to the proposed intervals, as outlined in the preamble. Manufacturers will be required to demonstrate the likelihood of in-use performance for certain critical emission-related maintenance.

D. Test Procedure Revisions

The heavy-duty engine test procedures have been revised to incorporate particulate test procedures. These include changes in response to comments along with other minor corrections, as outlined in the preamble to the final rule.

IV. List of Commenters

The following individuals, organizations, public authorities and manufacturers submitted written comment in response to the NPRM (49 FR 40258). This list contains only those comments received by January 4, 1985. Comments received after that date, although not specifically identified here, have also been incorporated fully into EPA's analyses along with those listed.

1. Adair, Holiday, Akron, OH
2. American Automobile Association
3. American Honda Motor Company
4. American Lung Association
5. American Lung Association. of Berks County (PA)
6. American Lung Association of Deleware/Chester Counties (PA)
7. American Lung Association of Florida
8. American Lung Association of New Jersey
9. American Lung Association of Western Missouri
10. American Motors Corporation (AMC)
11. American Public Transit Association
12. Arent, Fox, Kinter, Plotkin & Kahn for MEMA
13. Arizona Lung Assoc.
14. Audubon Society of Ohio
15. Automobile Importers of America
16. Bass, Jean, Ross, CA
17. Baughman, Jon, Bedford Hgts., OH
18. Baumgarten, Sam, Bridgewater, MA
19. Bergen County (NJ) Audubon Society
20. Bickford, Isabel, Williamsville, NY
21. Biesterfeld, Cathy, Homewood, IL
22. Bradman, Asa, Ross, CA
23. Brenner, Jeff, New Brunswick, NJ
24. Brown, Bruce and Sharon, Chicago, IL
25. Brown, Paul M., Sun Olympiad '80
26. Burchard, Ann, Robert and Rachel, Catonsville, MD
27. California Air Resources Board
28. California Dept of Justice

29. Callan, Ida, Vienna, OH
30. Cape Henry Audubon Society
31. Capital District Transportation Authority
32. Caterpillar Tractor Company
33. Chemel, Bonnie, Evans City, PA
34. Chicago Transit Authority
35. Chrysler Corporation
36. Ciak, Josephine, North Arlington, NJ
37. Clark County (NV) Health District
38. Coalition for Clean Air
39. Coalition for the Environment
40. Colorado Department of Health
41. Connaughton, Ruth K.
42. Cummins Engine Company
43. Delaware Valley Citizens Council for Clean Air
44. Delello, Michael, Saranac Lake, NY
45. Dillon, Mary, Elma, NY
46. Dolinka, Marvin & Toby, Grand Rapids, MI
47. East Michigan Environmental Action Council
48. El Paso Clean Air Coalition
49. Environmental Alternatives, Inc.
50. Faulconer, Mrs. James H., Strasburg, VA
51. Fisher, C. Donald, Muncy, PA
52. Ford Motor Company
53. Fox, Warren, Linwood, NJ
54. Gardiner, Jeffrey, Schenectady, NY
55. General Motors Corporation (GM)
56. Geymer, Christine, Oak Park, IL
57. Gordon, Robin, Great Neck, NY
58. Greater Cleveland Regional Transit Authority
59. Grenfo, Louise, Crossville, TN
60. Group Against Smog and Pollution
61. Hamilton, James, Cleveland, OH
62. Hawarth, Terrie, E. Grand Rapids, MI
63. Holmes, David, Clarion, PA
64. Humphreys, Betsy, Morgantown, WV
65. Huser, Bill, So. Sioux City, NE
66. International Harvester Company (IHC)
67. Isker, C., Buffalo, NY
68. Iwanik, Mike, Richmond, VA
69. Jaguar Cars Inc.
70. Jenner & Block for Engine Manufacturers Association (EMA)
71. Joan Katz Productions
72. Johnson, David, Pueblo, CA
73. Johnson, Nina, Boulder, CO
74. Johnson, Rose Mary, Louisville, KY
75. Kemp, Katherine, Chicago Heights, IL
76. Kulakowski, Lois, Tucson, AZ
77. LTV Aerospace and Defense Company
78. League of Women Voters of the Clemson Area

79. League of Women Voters of the Pittsburgh Area
80. Lewis, Nana, Larkspur, CA
81. Love, John, Boulder, CO
82. Mack Trucks Inc.
83. Mannchen, Brandt, Houston, TX
84. Mansell, Gerda, Lancaster, NY
85. Manufacturers of Emission Controls Assoc.
86. Massachusetts Department of Env. Quality Engineering
87. Mazda (North America)
88. McCarty, Donna, Indianapolis, IN
89. McGuire Clinic
90. Mercedes-Benz Truck Co.
91. Meyer, Arthur, Akron, PA
92. Motor and Equipment Manufacturers Association
93. Motor Vehicles Manufacturers Association (MVMA)
94. Mueller, Catherine & Edwin, Buffalo, NY
95. Mueting, Ann, Plymouth, MN
96. Murkeloff, Robert, Houston, TX
97. NJ Transit Bus Operations
98. Natural Resources Defense Counsel (NRDC)
99. New Jersey Department of Environmental Protection
100. New Mexico Environmental Improvement Division
101. Newberry, William, Grand Rapids, MI
102. Nissan Research & Development
103. Oakes, Margaret, Boulder, CO
104. Oregon Department of Environmental Quality
105. Osterpard, Elsie, Grand Rapids, MI
106. Otter Creek Audubon Chapter
107. PACCAR Inc.
108. Pettit, Marie, Harrisonburg, VA
109. Rhode Island Department of Environmental Management
110. Richmond (VA) Audubon Society
111. Rolls-Royce Motors
112. Rosche, Olga, South Wales,NY
113. Ross, G.M., Lowell, MI
114. STAPPA/ALAPCO
115. Saab-Scania of America
116. Schiffirth, Anne & Jim, Pittsburgh, PA
117. Schoenfeld, Josephine, Grand Island
118. Sherman, L. Ann, Schaumburg, IL
119. Shutter, S.L.
120. Simpson, Robert, Flint, MI
121. Smith, Bertha, Grand Rapids, MI
122. South Coast Air Quality Management District
123. Southern California Rapid Transit District
124. St. Cloud Area Environmental Council
125. Storgul, Pauline, Chicago, IL
126. Tonseth, Phebe, Cumberland Foreside, ME
127. Toyota Technical Center, USA
128. U.S. Department of Energy
129. U.S. DOT, Urban Mass Transit Administration

130. VIA Metropolitan Transit
131. Volkswagen of America
132. Volvo-North American Car Operations
133. Volvo White Truck Corporation
134. Volvo of America Corporation - Bus Division
135. Washington State Department of Transportation
136. Wedow, Nancy, Palatine, IL
137. West Michigan Environmental Action Council
138. White Lung Association
139. Willard, Dwight, Albany, CA
140. Williams, Mark, San Francisco, CA

References

1. "Draft Regulatory Impact Analysis and Oxides of Nitrogen Pollutant Specific Study Control of Air Pollution From New Motor Vehicles and New Motor Vehicle Engines: Gaseous Emission Regulations for 1987 and Later Model Year Light-Duty Vehicles, Light-Duty Trucks, and Heavy-Duty Engines; Particulate Emission Regulations for 1987 and Later Model Year Heavy-Duty Diesel Engines," U.S. EPA, OAR, OMS, October 1984.

2. The Clean Air Act As Amended August 1977, Serial No. 95-11, Section 202(a)(3)(B)&(C).

3. IBID; Section 202 (a)(3)(iii); p. 102.

CHAPTER 2

TECHNOLOGICAL FEASIBILITY

I. Introduction

This chapter analyzes the technical feasibility and the leadtime requirements of the final 1988 and later model year light-duty truck (LDT) standards for oxides of nitrogen (NOx) emissions and the final heavy-duty engine (HDE) standards for NOx and particulate emissions for the 1988, 1991 and 1994 and later model years. Structurally, the chapter is divided into three primary sections with the LDT analysis appearing first followed by the analyses for heavy-duty gasoline engines (HDGE) and heavy-duty diesel engines (HDDE). Each primary section of the chapter begins with an overview of the material presented in the technological feasibility analyses included in the "Draft Regulatory Impact Analysis and Oxides of Nitrogen Pollutant Specific Study."[1] The overview is followed by a summary and analysis of the comments, by issue, received in response to the proposed standards. Comments from environmental groups and private citizens, which addressed the stringency of the proposed standards and associated leadtime requirements, were based largely on legal intrepretations of the requirements of the Clean Air Act and as such, these comments are addressed in the Preamble to the FRM. Conclusions regarding the issues raised in the comments constitute the final subsection of each primary section and, where necessary, show the changes in the technological feasibility analyses resulting from the comments.

II. Light Duty Trucks (LDTs)

A. Synopsis of NPRM Analysis

The specific details concerning the methodology used to determine the feasibility of the proposed standards will not be repeated here, but can be found in the draft analysis. In brief summary, the methodology involved first estimating the low mileage emission target level (LMT) associated with the 1987 emission standards under consideration. (The LMT represents a level below the emission standard at which manufacturers must calibrate their emission control systems to account for test-to-test variability, production line emission variability and in-use emission deterioration). Using the calculated LMT and emission certification data for 1984, the emission reduction necessary to comply with the various standard levels considered for proposal were determined. Finally, the requisite technology for achieving these reductions was identified.

It was concluded from this analysis that the 1.2 g/mi NOx standard was feasible for all LDGTs and for lighter LDDTs ($LDDT_1$s). The principal compliance means for LDGTs would be closed loop, three way catalyst technology, while lighter LDDTs would rely on the application of EGR. For $LDDT_2$s it was concluded (because of their heavier weights and larger frontal areas) that a 1.2 g/mi NOx standard would increase particulate levels such that it would affect the stringency of the 0.26 g/mi particulate standard. Consequently, EPA then considered a 1.7 g/mi NOx standard for $LDDT_2$s. As in the case of $LDDT_1$s, EGR was projected to provide the means for compliance.

It was concluded that a 1.7 g/mi standard appropriately balanced the need for NOx and particulate control. As a result, EPA decided to propose a NOx standard of 1.7 g/mi for $LDDT_2$s. EPA also decided that it was most equitable to propose the 1.7 g/mi NOx standard for $LDGT_2$s. This was done because a more stringent NOx standard for heavier LDGTs would encourage the purchase of $LDDT_2$s, which EPA did not wish to do. Further, the loss of NOx control due to a more lenient standard for $LDGT_2$s was small compared to the case where only diesels were affected.

Considerations of the effects on fuel economy of the proposed NOx standards in combination with the technologies expected to be employed led to the conclusion that LDGTs which were converted to three-way catalyst technology from oxidation catalyst technology could experience up to an 8 percent improvement in fuel economy. For those LDGTs which already employed three-way catalyst technology, it was projected that some small fuel economy loss might occur. It was forecasted on a sales-weighted basis that roughly a 2-4 percent improvement in fuel economy would be associated with the proposed standards for LDGTs. For LDDTs, consideration of the effects of the proposed standard on fuel economy led to the conclusion that no significant fuel economy penalty would result from the proposed standards for either $LDDT_1$s or $LDDT_2$s. This conclusion was based on evaluations of the differences in fuel economy between $LDDT_1$s with and without EGR and on the benefits associated with the use of electronic controls on $LDDT_2$s.

For LDTs sold at high altitude, EPA proposed the same NOx standards as were proposed for low altitude LDTs because NOx emissions do not tend to increase with altitude. An idle CO standard for high altitude LDTs equal to the 0.50 percent standard already required for low altitude LDTs was proposed because a 90 percent reduction from baseline high altitude idle CO levels resulted in a numerical value of 0.51 which, when rounded, was equal to the low altitude value. A particulate standard equal to that at low altitude was also proposed.

B. Summary and Analysis of Comments

1. Introduction

The comments received concerning the feasibility of the proposed LDT NOx standards are summarized and analyzed below. When more than one commenter raised the same basic issue, the issue is treated once in the summary and analysis with identification of the multiple sources of the comment. While the proposed standards are applicable to two types of engines (gasoline and diesel) used to power LDTs and are numerically different as a function of the weight of the LDT, comments will be treated by issue with appropriate consideration of these distinctions where necessary. The issues contained in the summary and analysis of comments which follows are, the technical feasibility of the proposed standards, the leadtime required for compliance, the effect of the standards on fuel economy and other minor issues.

2. Technical Feasibility of the Proposed Standards

Six commenters provided comments on the technical feasibility of the proposed standards with respect to gasoline-fueled LDTs. Chrysler, Ford, General Motors, Nissan and Toyota stated that the proposed standards (1.2 g/mi for $LDGT_1$s and 1.7 g/mi for $LDGT_2$s) were technologically feasible.

VW disagreed with the technical feasibility of the proposed standard on the grounds that the allowable maintenance provisions and the full-life useful life requirement result in requirements which are beyond the capabilities of current in-use or reasonably forseeable technology. VW did not, however, provide any information in substantiation of their statement. Lacking substantiating information for the VW statement and considering the position taken by the other commenters leads to the conclusion that the proposed standards are technologically feasible for LDGTs using the technologies identified in the Draft RIA (three way catalyst and closed loop fuel control). This is confirmed by certification data for the 1985 model year. As shown in Tables 2-1 to 2-7, nearly all LDTs certified with three-way closed loop technology are already in compliance with 1.2/1.7 standards. Both full-life useful life and revised allowable maintenance provisions apply to federally certified LDTs for 1985.

In the case of diesel fueled LDTs, three commenters provided comments on the technological feasibility of the proposed standards (1.2 g/mi and 1.7 g/mi). One commenter, Ford, stated that the proposed NOx standards were

Table 2-1

1985 49-State Federal Certification Data for LDGTs Equipped with Three-Way Catalyst Technology

Manufacturer	Engine Family	Emission Control Technology*	Mean NOx DF	Mean Cert. NOx Level
Light-Duty Trucks - Class 1				
American Motors	FAM2.5TIHEA5	EGR/PLS/3CL	1.541	1.27
Ford	FPM2.3T5FAG7	EGR/3CL	1.057	0.34
Nissan	FNS2.4T9FAF0	EGR/3CL/OTR	1.095	1.11
Mitsubishi	PMT2.0T2FFDX	EGR/PLS/3CL/OTR	1.043	1.12
	PMT2.6T2FFD2	EGR/PLS/3CL/OTR	1.100	1.38
Suzuki	FSK1.0T1FSF7	3CL	1.216	1.70
Volkswagen	FVW1.9T5CVF8	3CL	1.043	0.74
Light-Duty Trucks - Class 2				
American Motors	FAM4.2T2HEA7	EGR/PLS/OXD/3CL	1.114	1.4
	FAM5.9T2HLE2	EGR/PMP/3WY	1.056	1.35
Ford	FPM5.0T5HAG8	EGR/PMP/OXD/3CL/OTR	1.021	0.80
	FPM5.8T2HGG1	EGR/PMP/OXD/3CL	1.005	1.85
	FPM5.8T4GAF4	EGR/PMP/OXD/3WY	1.131	2.1

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* EGR = Exhaust gas recirculation.
3CL = Three-way catalyst, closed-loop fuel control.
PMP = Air pump.
OTR = Other.
PLS = Pulse air injection.
3WY = Three-way catalyst, open-loop fuel control.
OXD = Oxidation catalyst.
EM = Engine modification.

Table 2-2

1985 49-State Federal Certification Data for LDGTs Equipped Without Three-Way Catalyst Technology

Manufacturer	Engine Family	Emission Control Technology*	Mean NOx DF	Mean Cert. NOx Level
Light-Duty Trucks - Class 1				
American Motors	FAM2.8T2AXE3	EGR/PMP/OXD	1.050	1.7
Chrysler	FCR2.2T2AAB6	EGR/PMP/OXD	1.0	1.57
	FCR2.6T2AAB8	EGR/PMP/OXD	1.0	1.2
Ford	FFM2.0T1AGF2	EGR/PMP/OXD	1.0	1.95
General Motors	FIG1.9T2HJC2	EGR/PMP/OXD	1.0	1.9
	FIG2.8T2HTX1	EGR/PMP/OXD	1.050	1.60
Isuzu	FSZ119T2AAG2	EGR/PMP/OXD	0.975	1.70
Toyota	FTY2.4T2AFF1	EGR/PLS/OXD/OTR	1.10	1.85
Fuji	FFJ1.8T2AFJ1	EGR/PLS/OXD	1.017	1.25
	FFJ1.8T2AFK2	EGR/PLS/OXD	1.017	1.75
Light-Duty Trucks - Class 2				
Chrysler	FCR3.7T1BBA0	EGR/PMP/OXD	1.0	1.9
	FCR5.2T2BBF6	EGR/PMP/OXD	1.0	1.9
	FCR5.9T4BBF1	EGR/PMP/OXD	1.0	1.62
General Motors	FIG4.3T4HHC1	EGR/PMP/OXD	1.012	1.45
	FIG5.7T4HHC0	EGR/PMP/OXD	1.0	1.73
Toyota	FTY4.2T2AFF5	EGR/PMP/OXD/OTR	0.816	0.99

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* See Table 2-1 for definition of terms.

Table 2-3

49-State Federal Certification Data for 1985 LDDTs

Manufacturer	Engine Family	Emission Control System*	NOx DF	Mean Cert. NOx Level
Light-Duty Trucks - Class 1				
American Motors	FAM2.1K6JZT7	EM	1.038	1.40
Ford	FFM2.3KJAF1	EM	0.995	1.65
General Motors	FIG2.2K7ZZ98	EM	1.000	1.80
Grumman Olson	FGR1.6K6JAA6	EM	1.000	1.10
Isuzu	FSZ137K6JCD5	EM	0.956	1.70
Nissan	FNS2.5K6JAF7	EM	1.015	1.80
Mitsubishi	FMT2.3K6JFD2	EM	0.995	1.85
Toyota	FTY2.4K6JFF1	EM	1.005	1.70
	FTY2.4K6JFT9	EM	1.000	1.80
Light-Duty Trucks - Class 2				
General Motors	FIG6.2K7ZZ42	EGR	1.013	1.90

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* See Table 2-1 for definition of terms.

Table 2-4

1985 California Only Certification Data for LDGTs Equipped with Three-Way Catalyst Technology

Manufacturer	Engine Family	Emission Control Technology*	NOx DF	Mean Cert. NOx Level
Light-Duty Gasoline Trucks - Class 1				
Fuji	FFJ1.8T2HCG0	EGR/PLS/OXD/3CL	1.293	0.33
	FFJ1.8T2AFK2	EGR/PLS/OXD/3CL	1.293	0.31
	FFJ1.8T2HCP0	EGR/PLS/OXD/3CL	1.293	0.28
Toyota	FTY2.4T2FCC7	EGR/3CL/OTR	1.076	0.44
Ford	FPM2.3T5FFG6	EGR/3CL	1.000	0.27
	FPM2.8T2HKG0	EGR/PMP/OXD/3CL	1.091	0.70
Isuzu	FSZ119T2FDG1	EGR/PMP/3CL	.997	0.43
AMC	FAM150TIHEA6	EGR/PLS/3CL	1.372	0.83
	FAM173T2F4C3	EGR/PMP/3CL	.892	0.94
Nissan	FNS2.4T9FAC8	EGR/3CL/OTR	1.159	0.71
General Motors	FIG2.8T2TPA3	EGR/PMP/3CL	1.000	0.64
Volkswagon	FVW1.9T5CVC5	3CL	.526	0.63
Light-Duty Gasoline Trucks - Class 2				
AMC	FAM258T2HEA0	EGR/PLS/3CL	1.045	0.68
	FAM360T2HLE0	EGR/PMP/3WY	1.050	0.56
Ford	FPM4.9TIHGG6	EGR/PMP/OXD/3CL	1.084	0.73
	FPM5.8T2HGG1	EGR/PMP/OXD/3CL	1.100	0.81
Chrysler	FCR3.7TIHDS1	EGR/OXD/3CL	.947	0.82
General Motors	FIG4.3T4TAA3	EGR/PMP/3CL	1.031	0.82
	FIG5.7T4TYA5	EGR/PMP/3CL	1.031	0.60
AMG	FAZ4.2T2HRG0	EGR/OXD/3CL	1.170	0.53

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* See Table 2-1 for definition of terms.

Table 2-5

1985 California Only Certification Data for LDDTs

Manufacturer	Engine Family	Emission Control Technology*	NOx DF	Mean Cert. NOx Level
Light-Duty Diesel Trucks - Class 1				
Isuzu	FSZ137K6JBD3	---	1.034	.84
Mitsubishi	FMT2.3K6JCB5	---	.964	.76
Toyota	FTY2.4K6JCT3	OTR	1.043	.86
Nissan	FNS2.5K6JAC4		.939	.75
General Motors	FIG2.2K7ZZL2		1.000	.89
Light-Duty Diesel Trucks - Class 2				
General Motors	FIG6.2K7ZZ75		1.015	1.30
General Motors	FIG6.2K7ZZ75		1.015	1.70

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* See Table 2-1 for definition of terms.

Table 2-6

1985 50-State Certification Data for LDGTs Equipped with 3-Way Catalyst Technology

Manufacturer	Engine Family	Emission Control Technology*	Mean NOx DF	Mean Cert. NOx Level
Light-Duty Trucks - Class 1				
AMG	FAZ2.5T1HRG9	EGR/PLS/OXD/3CL	1.17	.38
Chrysler	FCR2.2T2HBM9	EGR/PMP/OXD/3CL	1.087	.72
	FCR5.2T2HBN1	EGR/PMP/OXD/3CL		
GM	F2G2.575TPG9	EGR/3CL	1.320	.42
Mitsubishi	PMT2.0T2FCA1	EGR/PLS/3CL/OTR	1.028	.58
	PMT2.6T2FCA4	EGR/PLS/3CL/OTR	1.072	.68
Toyota	FTY2.4T5FBT6	EGR/3CL/OTR	.683	.07
	FTY2.0T5FBB3	EGR/3CL/OTR	1.568	.17
	FTY2.4T5FBB5	EGR/3CL/OTR	1.463	.17
Light-Duty Trucks - Class 2				
Dutton	FDN4.1T5NKA4	EGR/PMP/OXD/3CL	1.157	.48
Ford	FFM5.0T5HAG8	EGR/PMP/OXD/3CL/OTR	1.100	.57
Winnebago	FWB2.2TSFGA0	EGR/3CL	1.170	.61
Zimmer	FZM2.6T6FXX5	3CL/OTR	1.150	.84
GM	FZG2.5T5TPG9	EGR/3CL	1.320	.28
Chrysler	FCR5.2T2HBN1	EGR/PMP.OXD/3CL	1.051	.81
			1.158	.60

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* See Table 2-1 for definition of terms.

Table 2-7

1985 50-State Certification Data for LDDTs

Manufacturer	Engine Family	Emission Controls	Mean NOx DF	Mean Cert. NOx Level
Light-Duty Trucks - Class 1				
Mitsubishi	FMT2.3K6JCB5	EGR	.964	.75
	FMT2.3K6JFD2	EM	.995	1.85
Nissan	FNS2.5K6JFD2	EGR	.939	.75
	FNS2.5K6JAF7	EM	1.015	1.80
Isuzu	FSZ137K6JAF7	EGR	1.034	.84
	FSZ137K6JCD5	EM	.956	1.70
Toyota	FTY2.4K6JCT3	EGR/OTR	1.043	.86
	FTY2.4K6JFF1	EM	1.005	1.70
	FTY2.4K6JFT9	EM	1.000	1.80
GM	FIG2.2K7ZZL2	EGR	1.000	.89
	FIG2.2K7ZZ98	EM	1.000	1.80
AMC	FAM2.1K6JZT7	EM	1.038	1.40
Ford	FPM2.3K6JAF1	EM	.995	1.50
Grumman Olson	FGR1.6K6JAA6	EM	1.000	1.10
Light-Duty Trucks - Class 2				
Ford	FPM2.3K6JAF1	EM	.995	1.80
GM	FIG6.2K7ZZ75	EGR	1.015	1.50
	FIG6.2K7ZZ42	EGR	1.013	1.90

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* See Table 2-1 for definition of terms.

technologically feasible for LDDTs. Nissan stated that the standard proposed for $LDDT_1$s (1.2 g/mi) was feasible for some of its two-wheel drive vehicles, while its other $LDDT_1$s would need new EGR systems to control NOx while simultaneously complying with the particulate standard of 0.26 g/mi. GM stated that the ability of the 6.2 liter engine to comply with a NOx standard of 1.7 g/mi through the use of electronically controlled EGR would be marginal and would result in increased particulate emissions and a fuel economy penalty. GM provided a figure (Figure III-C-1 in the GM comments) depicting the NOx vs. particulate engine-out emission characteristics for the 6.2 liter engine in support of its position that particulate emissions would greatly increase under a 1.7 g/mi standard and jeopardize its ability to meet the LDT particulate standard of 0.26 g/mi.

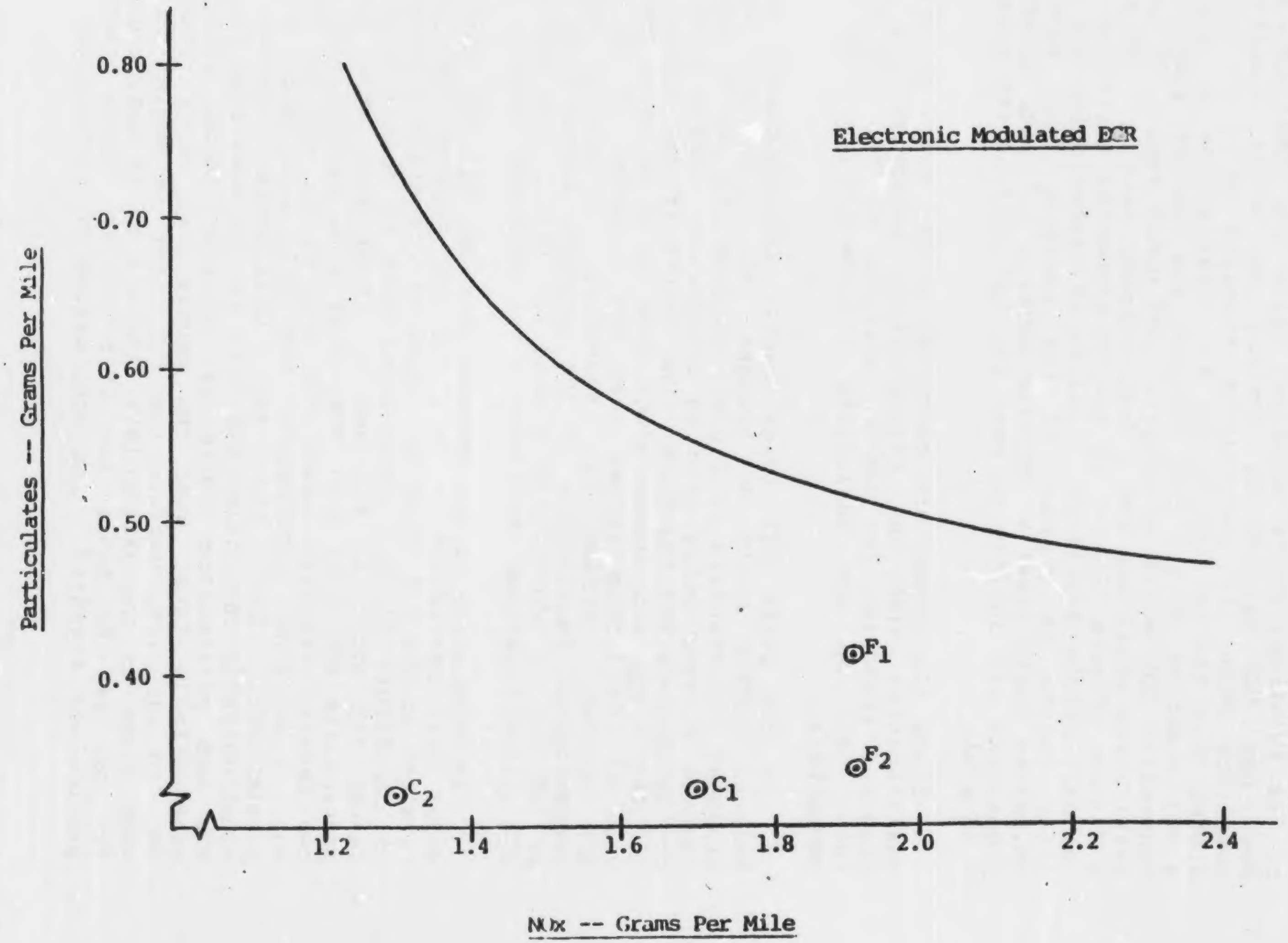
Since all commenters concurred either fully or with some qualification with the technological achieveability of the proposed standards for LDDTs, analysis of the comments need focus only on the qualifying statements presented by the commenters.

In the Draft RIA (page 2-22), EPA concluded that all Federal $LDDT_1$s could be brought into compliance with the proposed NOx standard (1.2 g/mi) through the use of EGR system designs already being used on counterpart $LDDT_1$s certified to the California NOx standard. The thrust of the Nissan comment is that a new EGR system would have to be designed for use on some of its $LDDT_1$s rather than the transfer of an existing EGR system. Nissan is, therefore, concurring with the technological feasibility of the proposed standard by the use of EGR but is identifying a need for leadtime to design a new EGR system (leadtime requirements are addressed later).

In responding to the comment from GM, EPA has plotted 1985 model year certification data for the Federal and California versions of the 6.2 liter GM engine on the curve provided by GM in its Figure III-C-1 (reproduced here as Figure 2-1). These values are shown as F_1, and F_2 (1.90 g/mi NOx, 0.41 g/mi particulate and 1.90 g/mi NOx, 0.34 g/mi particulate) for the two federal vehicles using EGR and as C_1 and C_2 (1.7 g/mi NOx, 0.32 g/mi particulate and 1.3 g/mi NOx, 0.32 g/mi particulate) for the two California engines using electronically controlled EGR. As can be seen from Figure 2-1, NOx and particulate emissions actually being achieved are substantially lower than the generalized curve presented by GM. In addition, because the 6.2 liter GM engine is already very close to the particulate standard on an engine-out basis, EPA can see no basis for GM's concern about meeting the particulate standard. The application of particulate traps to

Figure 2-1

NOx - Particulate Trade - Off Curve -- 6.2L Light Duty Diesel



approximately percent of these engines would, with averaging, secure compliance with the 0.26 g/mi standard. EPA concludes that the NOx/particulate curve supplied by GM is not applicable to current versions of its 6.2 liter engine, and that GM should have no difficulty meeting a 1.7 g/mi standard with this engine.

3. Leadtime Requirements

Four commenters stated that the time required for implementation of the LDT NOx standards for gasoline-fueled vehicles exceeds the time available under the proposal. Specifically, the comments were as follow. American Motors indicated that 34 months are normally required for the change in catalyst technology required by the proposed standards. General Motors stated that 106 weeks were required to make changes to LDT bodies necessary to accommodate the larger catalysts required for compliance with the proposed standards. Nissan indicated that 2-1/2 to 3 years would be required for changes to the vehicle body necessitated by the use of larger catalysts. Toyota stated that additional time is needed beyond that available for compliance by the 1987 model year because of the change in catalyst technology necessary and the need to establish durability and reliability characteristics of the new catalyst.

Two of the commenters (GM and Nissan) predicated their leadtime requirements on the need to change the floorpan of the vehicle body to accommodate larger catalysts. The tasks required for the specified change in the vehicle body would be the redesign of the floorpan to provide the necessary space and the procurement of new dies for the manufacture of the redesigned floorpans. Since the commenters indicated in other areas of their comments that they have already quantified the catalyst volume requirements, redesign of the floorpan can be assumed to start essentially at the publication date of the final rule. The maximum time requirement which could be allocated for the redesign of the floorpan is 6 to 9 months. Following redesign of the floorpan, the time required for the procurement of new dies is between 26 and 36 weeks (Reference 2 at page 7-7) including the time required for installation of the new dies in the presses. In total, these two tasks are expected to require between 50 and 72 weeks or a maximum of 18 months. Starting with a publication date of March 15, 1985 for the final rule and ending with October 1, 1986 for the introduction date of the 1987 model year LDTs, defines a period of 18-1/2 months for the execution of the tasks necessary for vehicle body redesign. Leadtime requirements for the redesign of LDT bodies is, therefore, not a viable basis for claiming that insufficient time is available for the implementation of the proposed standards on LDGTs.

Turning to the comments provided by American Motors, that 34 months is the normal requirement for the introduction of new catalyst technology to a specified class of vehicle, the steps required for this work can be identified as follows. The first step would be the development of an overall system design including the integration of the new system into the vehicles. The subsequent steps would be: 1) ordering of modified tooling for the manufacture of redesigned components which could include vehicle body redesign, 2) the construction and testing of experimental systems at several calibrations to establish one or more calibrations for use on emission durability vehicles, 3) collection of emission durability data, 4) collection of data from emission data vehicles, and 5) the incorporation of modified tooling on machine lines for the manufacturer of redesigned components.

EPA's timing requirement estimates for the primary tasks in the critical timing path for gasoline-fueled LDTs are as follows:

Task	Time Requirement
Overall System Design and Vehicle Integration	4-6 months
Develop Durability Vehicle Calibrations	5-7 months
Generate Emission Durability Data	11-12 months
Develop Final Calibrations	1-2 months
Run Data Vehicles	1 month
Complete Certification Process With EPA and Add Modified Tooling	1-2 months
TOTAL	23 - 30 months

Starting with a publication date of March 15, 1985 for the final rule establishing the NOx standard, approximately 18-1/2 months is available prior to the start of the 1987 model year in October of 1986. Since the minimum time required to perform the necessary tasks is greater than the time available, it is concluded that insufficient time was allowed by the proposal. The addition of 12 months to the time available for performing the necessary tasks by delaying the effective date of the standards to the 1988 model year would provide adequate time (30 months) for the performance of the tasks.

Two commenters provided statements to the effect that the time necessary for implementation of the LDT NOx standards on diesel vehicles was greater than that allowed by the proposal. American Motors stated that it would have to add EGR and particulate traps for simultaneous compliance with the NOx and particulate standards of 1.2 g/mi and 0.26 g/mi respectively for its LDDT's and that the earliest possible date for completion of this work was the 1988 model year. Nissan stated that the 1989 model year was the earliest possible date for compliance with the NOx and particulate standard so as to allow sufficient time for the development of new emission control systems.

While both commenters integrated compliance with the proposed 1.2 NOx standard for LDDT,s and compliance with the 1987 model year 0.26 particulate standard into their comments, this integration is not as important as could be inferred from the comments since the requirements for the particulate standard were promulgated in January 1984. Manufacturers have, therefore, had ample time to plan and to initiate system development and any tooling requirements associated with the particulate standard. Timing requirements attributable to the NOx standard are, therefore, the only requirements which need to be addressed in analyzing these comments. Primary tasks necessary for the application of EGR for the first time (AMC does not offer a diesel engine in their LDTs in California in 1985) or the application of a new EGR system design (Nissan) are: 1) overall system design which identifies exhaust manifold changes to incorporate a source for the recirculated gases and intake manifold changes to incorporate a point for the introduction of the recirculated gases, 2) orders for modified tooling for the manufacture of the redesigned manifolds*, 3) build and test experimental systems at several calibrations to establish one or more calibrations for use on emission durability vehicles, 4) collect emission durability data, 5) collect data from emission data vehicles, and 6) add modified tooling to machine lines for the manufacturer of redesigned intake and exhaust manifolds. Timing requirements for tooling, to manufacturer EGR valves and plumbing, do not enter into the overall timing considerations because these parts can be expected to be supplied by existing facilities (either vendor or manufacturer owned). The timing requirement estimates for the primary tasks in the critical timing path for diesel LDTs are as follows:

Primary Task	Time Required
Overall System Design	3-4 months
Develop Durability Vehicle Calibrations	5-7 months
Generate Emission Durability Data	11-12 months
Develop Final Calibrations	1-2 months
Run Data Vehicles	1 month
Complete Certification Process With EPA and Add Modified Tooling	1-2 months
TOTAL	22 - 28 months

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* Timing requirements for the procurement of a tooling modification do not enter the critical path timing line since a complete new machine line can be delivered in 18 to 20 months.[2]

Starting with a publication date of March 15, 1985 for the final rule establishing the NOx standard, approximately 18-1/2 months would be available prior to the start of the 1987 model year in October of 1986. Since the time available for performing the necessary tasks is less than the minimum estimate for the requirements, it appears that there is merit in the comments. The addition of 12 months to the time available by delaying the effective date of the standards to the 1988 model year would provide adequate time (30 months) for the performance of the tasks.

4. Fuel Economy Effects of the Proposed Standards

For gasoline fueled LDTs, six commenters stated that the proposed standards would result in a reduction in fuel economy. These statements were made by American Motors, Chrysler, Ford, General Motors, Nissan and Toyota. Only three of the commenters (American Motors, Ford and General Motors) however, provided numerical estimates of the effects of the proposed standards on fuel economy. Ford indicated that a fuel economy penalty of between 1 percent and 1.5 percent was expected for heavy LDGTs at a NOx standard of 1.7 g/mi and approximately a 2.5 percent penalty for heavy LDGTs at a 1.2 g/mi NOx standard. In addition, Ford stated that there would be penalties in the areas of driveability and performance.

GM stated that its LDGTs are exhibiting up to a 6 percent fuel economy penalty when comparison is made between 1985 model year Federal (2.3 g/mi NOx, 120,000 miles) and 1985 model year California* LDGTs. GM continued its statement by saying that the proposed NOx standard of 1.2 g/mi NOx with a useful life of 120,000 miles is more stringent than the California standard of 1.0 g/mi NOx with a useful life of 50,000 miles. In addition, GM stated that while the application of three-way-catalyst technology can be expected to improve fuel economy under a constant NOx standard, it cannot be expected to either improve fuel economy or to prevent a penalty under a more stringent standard.

The comment by American Motors was similar to the GM comment in that American Motors stated that its 1985 model year

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* 1985 California NOx standards for LDTs up to 3999 lbs equivalent inertia weight are 0.40 g/mi for 50,000 miles with optional standards of 1.0 g/mi for 50,000 miles or 1.0 g/mi for 100,000, miles. For LDTs between 4000 and 5999 lbs equivalent inertia weight the standard is 1.0 g/mi for 50,000 miles with an optional standard of 1.5 g/mi for 100,000 miles.

California LDTs were exhibiting approximately 1 mpg* lower fuel economy than its 1985 model year Federal LDTs and that the 1.0 g/mi, 50,000 mile California standard was less stringent than the proposed 1.2 g/mi, 120,000 mile Federal standard.

Since manufacturers had placed such emphasis in their comments on the effects of the California NOx standards on fuel economy, EPA assembled paired fuel economy data for 1985 model year Federal and California specification LDTs from its certification records. The criteria used in selecting paired data were that the same engine, by manufacturer, had been tested under the same dynamometer loading conditions in vehicles equipped with the same transmission specification, number of driven wheels (2 wheel drive and/or 4 wheel drive) and N/V ratio. This information is shown in Table 2-7. The information shown in Table 2-7 is subdivided into three groups, those gasoline LDTs employing the same technology for compliance with the Federal and California standards, those using different technologies and diesel LDTs. Because California NOx emission standards include several options and the specific option used was not always clearly defined in the records, exact distinction between the vehicle emission levels and the useful life requirement of the standard was not achievable. Distinction was possible, however, between vehicles certified to the 0.40 g/mi, the 1.0 g/mi and the 1.5 g/mi standards and is shown on Table 2-8.

EPA's overall assessment of the California versus Federal comparisons is that they are of limited use in making precise conclusions about the effects to be expected from the new LDT standards. This is first of all due to the fact that the California standards are more stringent than the Federal standards, resulting in somewhat lower emission levels than will the Federal standards. Under this situation, there will be a somewhat greater impact on fuel economy associated with the California levels. In addition, consideration must be given to the fact that the Federal standards will not apply until the 1988 model year. This means that time would be available for improvements aimed at overcoming any fuel economy penalties which might currently exist. Lastly, it must be born in mind that California standards apply to only a small fraction of any manufacturers' total LDT sales. Therefore, the manufacturers can be expected to adopt the lowest initial cost approach to compliance with a relatively small concern over fuel economy effects. This will not be the case in the longer term, when the entire LDT fleet is affected.

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* One mpg corresponds to between a 4 percent and a 6 percent fuel economy reduction for American Motors when based on comparisons to the highest "highway" fuel economy estimate or to the lowest "city" fuel economy estimate.

Table 2-8

1985 Model Year Light-Duty Truck Fuel Economy
Federal vs. California Paired Data*

		Technology		Fuel Economy			NOx Emissions		Calif.
				Combined MPG		%			
Mfr.	Engine**	Fed.	Calif.	Fed.	Calif.	Change	Fed.	Calif.	Std.
Gasoline, Same Technology									
AMC	2.5L(10)	3CL	3CL	23.4	22.5	-3.8	1.04	0.55	1.0
AMC	4.2L(7)	3CL	3CL	20.6	20.6	0	1.30	0.70	1.0
AMC	5.9L(1)	3WY	3WY	13.8	13.8	0	1.41	0.55	1.0
Chrysler***	5.2L(2)	3CL+OX	3CL+OX	14.8	14.8	0	0.74	0.74	1.0
Ford	2.3L(4)	3CL	3CL	29.8	29.4	-1.3	0.49	0.26	0.4
Ford	2.8L(7)	3CL+OX	3CL+OX	22.6	21.4	-5.3	1.51	0.66	1.0
Ford	4.9L(6)	3CL+OX	3CL+OX	17.2	16.7	-2.9	1.26	0.68	1.0
Ford	5.0L(2)	3CL+OX	3CL+OX	17.1	16.4	-4.1	0.83	0.54	1.0
GM ***	2.5L(19)	3CL	3CL	27.0	27.0	0	0.30	0.30	0.4
GM	4.3L(2)	3CL+OX	3CL+OX	22.6	22.0	-2.6	0.53	0.54	1.0
Nissan	2.4L(3)	3CL	3CL	23.3	23.1	-0.1	1.46	0.52	1.0
Mitsubishi	2.6L(13)	3CL	3CL	23.2	22.4	-3.4	1.27	0.64	1.0
Toyota ***	2.0L(4)	3CL	3CL	27.0	27.0	0	0.11	0.11	0.4
Toyota ***	2.4L(6)	3CL	3CL	25.4	25.4	0	0.14	0.14	0.4
VW	1.9L(2)	3CL	3CL	20.1	18.9	-6.0	0.92	0.39	0.4
Gasoline, Different Technology									
AMC	2.8L(1)	OX	3CL	20.5	22.1	7.8	1.80	0.76	1.0
Chrysler	5.2L(1)	OX	3CL+OX	15.5	15.2	-1.9	1.81	0.85	1.0
GM	2.8L(7)	OX	3CL	22.8	24.7	8.3	1.44	0.65	1.0
GM	4.3L(2)	OX	3CL	20.1	19.5	-3.0	1.57	0.47	1.0
GM	5.7L(1)	OX	3CL	13.9	14.2	2.2	1.80	0.80	1.0
Isuzu	1.9L(7)	OX	3CL	27.5	26.8	-2.6	1.77	0.41	1.0
Toyota	2.4L(4)	OX	3CL	28.8	27.2	-5.6	1.62	0.40	0.4
Fuji	1.8L(6)	OX	3CL+OX	27.3	28.6	4.8	1.78	0.20	0.4
Diesel									
GM	6.2L(7)	EGR	Elec EGR	23.5	23.3	-0.1	1.59	1.28	1.5

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* Data pairing requirements: equal engine displacement, transmission, N/V and inertia weight.

** Number in ( ) following engine size identifies the number of engine pairs used in calculating the mean fuel economy values shown.

*** No changes occur because this is a 50 state vehicle. Use of the same engine for Federal and California versions implies minimal fuel economy impact associated with the required low NOx level.

Regardless of the above caveats, instructive conclusions can be drawn from the California data. For those vehicles already having three-way technology on the Federal versions, there is no clear pattern of fuel economy change between the Federal and California versions. The data show that in some cases there are marked reductions in NOx emissions with little or no fuel economy impact. On the other hand, some vehicles exhibit significant penalties. However, the higher penalties are generally associated with vehicles having California NOx levels well below those needed for compliance with the 1.2/1.7 Federal standard. In any event, it has already been noted that vehicles already equipped with three-way technology are largely already in compliance with the 1.2/1.7 standards. Therefore, no changes will be required of these vehicles and no fuel economy impact will occur.

For those systems configured with oxidation catalysts on the Federal version, the data of Table 2-8 confirms EPA's analysis from the Draft RIA. All cases switching from oxidation catalysts to three-way catalysts, except for some certifying to unnecessarily low NOx levels, show a significant gain in fuel economy.

Overall, EPA draws the following conclusions regarding fuel economy effects on gasoline-fueled LDTs of the new LDT standards. First, for those vehicles already employing three-way technology, compliance or near-compliance is already widespread. Therefore, no fuel economy impact will result from the new standards. Second, for those vehicles switching from oxidation catalysts to three-way systems, a significant improvement in fuel economy should result from the new technology at the NOx levels associated with the Federal standard. In total, there will probably be some small fuel economy gain associated with the new standards. Since the amount cannot be precisely quantified at this time, no specific benefit will be included in the economic analyses of the new standards.

In the case of LDDTs, GM is the only commenter to comment on the fuel economy effects of the proposed standards. The comment provided by GM was directed to their 6.2 liter engine and indicated that GM expected a fuel economy penalty as a result of the proposed 1.7 g/mi standard which would be greater than the 5 percent which they are experiencing under the 1985 model year California standard.

Inspection of the NOx emission levels for the California 6.2 liter engine (Table 2-8) shows that the engine is certified to a 1.5 g/mi standard in conjunction with the particulate standard of 0.4 g/mi. At these California standard levels, the change in fuel economy relative to the Federal standard of 2.3 g/mi, NOx and 0.60 g/mi particulate is 0.1 percent, i.e. there is essentially no difference between the fuel economy values developed for the 6.2 liter GM engine under 1985 model year Federal and California standards. Since the proposed Federal standard applicable to this engine (1.7 g/mi) is not numerically as stringent as the California standard, EPA sees no basis for the comment provided by GM. The conclusion which can be drawn from the information shown in Table 2-8 is that there should be no fuel economy effect on the 6.2 liter GM as a result of the proposed standard.

5. Other Comments

Other comments pertaining to the proposed LDT NOx standards were provided in the areas of the factors to be used in distinguishing between LDT_1s and LDT_2s, the comparability between the 1.2 g/mi proposed standard and the 1.0 g/mi LDV standard and the proposed high altitude standards for NOx, idle CO and particulate.

Since these comments are fully addressed in the preamble to the final rule, they are not analyzed here. EPA agrees with the need to correct the discriminator between LDT_1s and LDT_2s. However, none of the comments in the other areas substantiate a need for changes. Interested readers are referred to the preamble for further details on EPA's response to these comments.

C. Conclusions

As a result of the proceeding analyses of the comments provided in response to the NPRM, it is EPA's conclusion that the proposed NOx standards of 1.2 g/mi for LDT_1s and 1.7 g/mi for LDT_2s are technologically feasible for the respective groups of LDTs. The technologies expected to be used in complying with these emission standard levels will center on the use of three-way catalyst technology with closed-loop fuel control in the case of gasoline-fueled LDTs and on the use of EGR in the case of diesel-fueled LDTs.

Analysis of the comments has led EPA to conclude that the time required (leadtime) for implementation of the necessary technologies is greater than that which would be available with an implementation date of the 1987 model year. A one-year delay in the implementation date of the standards to the 1988 model year would, however, provide sufficient leadtime.

Analysis of the comments provided on the fuel economy effects of the proposed standards has lead EPA to conclude that on average, those LDGTs which are already equipped with three-way catalyst technology will experience little or no reduction in fuel economy while those LDGTs which are converted from oxidation to three-way catalyst technology are expected to experience increases in fuel economy. In the case of LDDTs, the expectation is that there will be no measurable change in fuel economy resulting from the NOx standards. For the total fleet of LDTs, the effect of the proposed standards on fuel economy is expected to be near zero but with the potential for some improvement resulting from those LDGTs which adopt three-way catalyst technology.

III. Heavy Duty Gasoline Engines (HDGEs)

A. Synopsis of NPRM Analysis

The NPRM analysis[1] examined the feasibility of the proposed 1987 6.0 g/BHP-hr and the 1990 4.0 g/BHP-hr NOx emissions standards for HDGEs. The analyses for each standard began with the identification of the appropriate low-mileage target values. Current HDGE emission levels were then discussed as part of the analysis of the 1987 standards, as well as the effects of leadtime constraints and available emission control technologies. The analysis for the 1990 standard considered the likelihood of new and more refined emission control technologies. A summary of the NPRM analysis follows.

1. 6.0 g/BHP-hr NOx Standard

The factors considered in estimating the low-mileage emission target were the additive deterioration factor and the production variability factor. The additive deterioration factor (DF) was developed from 1983 model year HDGE certification data and was found to be zero. The NPRM's production variability factor of 1.2 was the mean of two estimates previously provided by Ford and GM in response to an earlier rulemaking. These two factors were employed in the following equation to develop the low-mileage emission target of 5.0 g/BHP-hr.

$$\text{Low Mileage Target} = \frac{\text{Emission Standard} - \text{Deterioration Factor}}{\text{Production Variability}}$$

The second step in the analysis was the identification of the reductions in emissions required to meet the target level. This was accomplished by a comparison of the low-mileage target and the most up-to-date information on low-mileage emission levels actually being achieved. The most up-to-date data available were those developed from prototype 1985 model year HDGEs. As a result of the comparison it was found that four of eleven engine families could presently (1985) comply with the low-mileage target. The average reduction necessary for compliance with the standard by the remaining seven families was 15 percent. The greatest reduction necessary for compliance by an engine family was 34 percent and the lowest reduction was 7 percent.

In considering leadtime, the analysis noted that some development testing had already been performed and further development testing would be initiated during the course of the rulemaking. Still, somewhat less than the equivalent of two years leadtime was determined to be available for NOx control development, thus, precluding the availability of major engine or hardware changes for production.

The final step in the analysis was the identification of technologies which could provide the reductions in NOx emissions necessary for compliance. Three potential technologies were identified: ignition timing retard, fuel enrichment of the air-fuel charge delivered to the engine and EGR. Ignition timing retard as the sole method of achieving compliance was judged to be unacceptable since it would result in a relatively large fuel economy penalty. Fuel enrichment was also judged to be undesirable since it would negatively impact compliance with both the HC and the CO standards as well as causing a reduction in fuel economy. Increased EGR, possibly coupled with a small amount of timing retard, was judged to be the approach which would most probably be employed by manufacturers since the necessary reduction in NOx could be achieved with an insignificant effect on fuel economy.

The analysis concluded that, based on information then available, and considering the relatively modest reductions necessary for only a fraction of the fleet and based on the availability of well understood NOx control technologies for gasoline-fueled engines, a 1987 NOx standard of 6.0 g/BHP-hr was feasible for HDGEs.

2. 4.0 g/BHP-hr NOx Standard

The low-mileage emission target for the 4.0 g/BHP-hr standard was developed using the same procedure as that used for the 6.0 g/BHP-hr standard. The same values for the deterioration factor and the production variability factor were also used because compliance with the 4.0 g/BHP-hr standard was expected to be achievable without the use of reduction catalyst technology. The low-mileage emission target developed by this procedure was 3.3 g/BHP-hr.

The reductions from 1985 model year prototype levels necessary for compliance with the 4.0 g/BHP-hr standard were estimated once the low-mileage target level had been identified. The average reduction necessary for compliance was found to be 39 percent with the greatest reduction being 57 percent and the least reduction being 3 percent.

At the level of emission control required for compliance with a 4.0 g/BHP-hr, it was concluded that emission control technologies beyond those required for compliance with the 6.0 g/BHP-hr standard (i.e., standard EGR) could be required to avoid significant performance and fuel economy penalties. The technologies identified as being the most probable for use were increased EGR rates with improved controls and "fast-burn" combustion chamber design, coupled with probable use of electronic control to optimize fuel metering and ignition timing.

With respect to leadtime, the adoption and demonstration of these control technologies were considered at that time to be feasible for 1990, based on the fact that prototype engines were already approaching the design target and considerable experience was directly transferable from work in light-duty vehicle and light-duty truck NOx control.

B. Summary and Analysis of Comments

The Agency received comments on its NPRM analysis from the three manufacturers of heavy-duty gasoline engines: Chrysler, Ford, and General Motors. Their comments on the 6.0 g/BHP-hr standard are examined first followed by an analysis of those pertaining to the 4.0 g/BHP-hr standard.

As will be seen in the next section on HDDEs, the 6.0 g/BHP-hr NOx standard will not be feasible for HDDEs until 1988. Thus, this implementation date will be assumed here, as well. Also, the 4.0 g/BHP-hr standard was found not to be feasible for HDDEs by 1990. However, a 5.0 g/BHP-hr standard appears to be feasible for 1991. Thus, this will be the second-stage NOx standard considered here for HDGEs.

1. 6.0 g/BHP-hr NOx Standard

None of the manufacturers disagreed with the low-mileage target level of 5.0 g/BHP-hr, nor with the low-mileage prototype data presented in the NPRM analysis. With respect to the availability of control technology and leadtime, two of the three manufacturers were generally in agreement with the conclusions reached in the NPRM analysis. In their submittals, both Ford and Chrysler stated that they could meet the proposed 6.0 g/BHP-hr standard; Ford in 1987 and Chrysler in 1988. GM stated that this standard should be feasible for its HDG vehicles above 14,000 lbs. GVW, but would result in a 1.5 percent fuel economy penalty; GM added that for its engines used in 8,500-14,000 lb. GVW vehicles, it did not believe that the proposed standard was feasible in conjunction with the 1987 model year 1.1/14.4 g/BHP-hr HC/CO standards. As an alternative to the 6.0 g/BHP-hr level, GM recommended a HDE NOx standard of 8.0 g/BHP-hr. However, this was due to GM's continued belief that catalyst technology is still not feasible for these engines, and not on an inability to meet the NOx standard, per se. Thus, given the fact that the initial NOx standard is being delayed to 1988 for HDDEs, all three manufacturers essentially agree that the 6.0 g/BHP-hr standard is feasible for HDGEs.

With respect to the technology needed to comply with this standard, both Ford and GM disagreed with the NPRM's assessment that increased EGR, possibly coupled with a small amount of timing retard, was sufficient and the most likely approach to be employed. According to Ford, more than just increased EGR and ignition timing retard are required in order to comply with the regulations while maintaining the fuel economy, performance and driveability of Ford's heavy-duty vehicles. In its confidential comments, Ford listed the control techniques it is planning to incorporate in order to meet a 6.0 g/BHP-hr standard.

GM also criticized the Agency's assessment of EGR as a control technique because of the fuel economy penalty resulting from increased EGR. However, unlike Ford, GM did not believe that alternative techniques were available for its HDGEs. GM supplied data taken on a 1985 350-4 V8 prototype engine that showed a 1.5 percent fuel penalty resulting from an increase in the EGR in order to comply with the proposed standard. Also, both recalibration of the air-fuel ratio and retarded ignition timing were found to be unacceptable by GM for the same basic reasons as identified in the NPRM. Chrysler did not comment on the technology needed for its engines to comply with a 6.0 g/BHP-hr standard.

Neither Ford nor GM presented sufficient justification for their projections of technology requirements to allow them to be objectively critiqued here. However, an analysis of 1985 Federal HDGE certification data confirms the conclusion of the NPRM that EGR is basically capable of providing the degree of control necessary to meet the 6.0 g/BHP-hr standard (see Table 2-9). Two engines, a 7.5L Ford and a 7.4L GM, are already being certified at NOx levels of 4.2 and 4.5 g/BHP-hr, respectively. The only significant difference between these engines and those at higher NOx levels appears to be increased EGR and recalibrated engine parameters (i.e., timing, secondary air rates, etc.). Thus, more significant changes should not be required for most HDGEs. As roughly one-third of all 1985 prototype HDGEs were able to comply with a 6.0 g/BHP-hr NOx standard and another one-third were within 25 percent of the standard, these engines should require no more than increased EGR rates plus recalibration. However, as described in the Draft RIA, the NOx levels of some of the engines were well

Table 2-9

1985 HDGE Federal Certification Results (g/BHP-hr)

Manufacturer	Displacement	Emission Control	NOx (DF)	HC (DF)	CO (DF)
Ford	4.9	EGR-Air	8.49(.01)	1.82(0.0)	15.65(.00)
		EGR-Air	6.96(.00)	1.66(.01)	14.93(.00)
	5.8	EGR-Air	8.24(.00)	1.78(.00)	30.65(.11)
	7.5	EGR-Air	6.66(.00)	.96(.00)	31.62(.07)
		EGR-Air	4.21(.00)	.41(.00)	14.01(.03)
GM	4.8	Air	7.03(.00)	.97(.00)	14.45(.00)
	5.7	EGR-Air	8.33(.05)	1.47(.02)	23.41(.00)
		EGR-Air	5.82(.05)	1.31(.02)	25.77(.00)
	6.0	EGR-Air	7.62(.00)	1.29(.25)	29.08(5.03)
	7.0	EGR-Air	7.72(.00)	1.23(.25)	25.32(5.03)
	7.4	EGR-Air	4.51(.00)	.68(.25)	27.48(5.03)
Chrysler	5.9L	EGR-Air	7.71(.07)	.65(.00)	18.73(.00)

above the design target of 5.0 g/BHP-hr (i.e., more than 25 percent). Compliance by these engines, which represent roughly half of those not already in compliance with the 6.0 g/BHP-hr standard, may require more significant modification to avoid impacting either HC/CO emissions or fuel economy. These modifications were among those identified in the NPRM analysis for the 4.0 g/BHP-hr standard and include modifications to the combustion chamber, the intake manifold, the secondary air system, and the camshaft. As discussed in Chapter 3, these changes may require some retooling, but, given their nature and the comments of Ford and Chrysler, leadtime should not be affected.

The certification levels shown in Table 2-9 are generally higher than those of the prototype engines described in the NPRM. This does not necessarily imply that the levels of the prototype engines were not in the end achievable. The current NOx standard puts little, if any, real pressure on HDGE NOx emissions, so the higher certification results probably involved recalibration to higher NOx levels. Thus, this does not negate the potential to achieve the lower NOx levels with the two sets of engine modifications described above.

Also to be noted from Table 2-9 is the positive relationship between HC and NOx emissions (i.e., HC emissions decrease as NOx emissions decrease). This is not to say that EGR decreases HC emissions, but that other engine parameters, such as the secondary air injection rate, can be adjusted to eliminate any adverse effect of EGR on HC emissions. This positive relationship is present even at the two lowest NOx levels of 4.2 and 4.5 g/BHP-hr.

With respect to fuel economy, GM argued for a 1.5 percent penalty, while the other two manufacturers did not comment on the NPRM's projection of no penalty. GM based its judgment on testing of a single engine with varying EGR rate. It was not clear from the information presented if BSFC was optimized at each EGR rate, or if EGR was simply increased. No actual data nor engine calibrations were presented. Thus, the GM projection cannot be evaluated against the other three projections of no penalty. Thus, the conclusion of the NPRM will be carried forward here, that of no fuel penalty.

In summary, essentially all three manufacturers of HDGEs are in agreement with the Agency's conclusion that a 6.0 g/BHP-hr standard is feasible for 1988 model year HDGEs. This standard is obtainable for HDGEs within the available leadtime constraints, and should result in no undue fuel economy, performance, or driveability penalties.

2. 5.0 g/BHP-hr NOx Standard

In comments on the proposed 1990 model year 4.0 g/BHP-hr NOx standard, the manufacturers uniformly termed this standard infeasible. Chrysler did not believe that the technology which will be available by the 1990 model year will be capable of achieving the 4.0 g/BHP-hr standard. Thus, Chrysler felt that the Agency did not realistically assess the prospects that the necessary control technology could be produced in time to assure compliance.

GM reported that its effort to reduce NOx emissions from HDGEs used in trucks above 14,000 lbs. GVW from current levels to the level required to comply with the proposed standard, HC emissions were doubled and fuel consumption was increased by about 6 percent. Thus, GM believed that the 4.0 g/BHP-hr NOx standard was not feasible because it would prevent compliance with the 1.9 g/BHP-hr non-catalyst HC standard for 1987 model year heavy HDGEs; also, the fuel assumption penalty was unacceptable.

Ford contended that EPA erred in its technological feasibility assessment of the control methods required to meet the standard. Ford was convinced that in order to reduce NOx emissions to the 4.0 g/BHP-hr level, a three-way-catalyst was required. According to Ford, a three-way catalyst is not capable of operating under the high-temperature conditions encountered by Class IIB, III, or VI heavy-duty trucks. Therefore, it determined that the 4.0 g/BHP-hr standard was not feasible. Ford also questioned EPA's analysis of fast-burn technology as a control method; Ford believed that the burn rates of the fast-burn cylinder heads described in the NPRM analysis will not be significantly different than a conventional head at the high speed and load conditions of the heavy-duty transient test cycle, thus making no allowance for further EGR optimization.

Since the 4.0 g/BHP-hr standard is no longer being considered for HDGEs the above comments pertaining to the 4.0 g/BHP-hr standard must be analyzed with respect to a 5.0 g/BHP-hr level. However, little detailed technical analysis was provided by the commenters to contribute to a detailed assessment of either a 4.0 or 5.0 g/BHP-hr standard. Thus, the analysis here will rely on the analysis performed for the NPRM and 1985 certification data. Further, an adoption of a 5.0 g/BHP-hr NOx standard should mitigate many of the manufacturers' concerns.

The NPRM analysis stated that the low-mileage target for a 5.0 g/BHP-hr NOx standard would be 4.2 g/BHP-hr. Based on 1985-1987 prototype data, that analysis also showed two engines already to be below this level and the remainder requiring an average 30 percent reduction in NOx emissions. Available 1985 Federal certification data (Table 2-9) basically confirm this. One engine is at the 4.2 g/BHP-hr target, while another is just slightly above this at 4.5 g/BHP-hr; these levels are being achieved essentially with EGR and minor engine recalibration. The remaining 1985 engines require somewhat more than a 30 percent reduction on average. However, this is not significant since the current 10.6 g/BHP-hr NOx standard puts no pressure on NOx emissions, and, therefore, there was no guarantee that the low NOx levels achieved by prototype engines would appear in certification. Given the fact that two engines in production already essentially meet the low-mileage target and a third protoype engine also met this level over a year ago, it is difficult to argue that this level will not be feasible six years hence. This is especially true given the general homogeneity of HDGE technology, which stands in stark contrast to the heterogeneous HDDE technology. The technologies discussed in the NPRM are applicable to any HDGE. Thus, the 5.0 g/BHP-hr NOx standard should be feasible for HDGEs.

This standard will require control technology similar to that required for the 6.0 g/BHP-hr standard (i.e., combustion chamber modifications, improvements to the intake manifold, the secondary air system and the camshaft). However, because a greater level of NOx reduction is required to reach 5.0 g/BHP-hr, a larger percentage of the fleet will require these hardware modifications in addition to increased EGR rates and recalibrations; burn rate improvements, as described in the NPRM analysis, may also be required as a control technology. Since roughly 15 percent of the current HDGEs of Table 2-9 essentially comply with the 5.0 g/BHP-hr standard without these hardware modifications and assuming NOx averaging to be available, it is estimated that roughly one-third of the remainder will be able to do so as well. Therefore, of the approximately 85 percent of the fleet requiring any additional control, about two-thirds will require the hardware changes described above, in addition to increased EGR and engine recalibration.

Although the 5.0 g/BHP-hr should be feasible via engine-related changes as detailed above, this does not rule out the possibility that manufacturers will decided to apply three-way catalyst technology to meet the standard. Class IIB and III HDGVs will be equipped with oxidation catalysts in 1987 to comply with the HC/CO emission standards and their LDGT counterparts will likely be equipped with closed-loop, three-way catalyst technology. Thus, the step to three-way catalyst may be considered by some manufacturers. However, such a change is not likely, since manufacturers have repeatedly emphasized to the Agency their position that significant questions of feasibility exist for three-way catalysts in the heavy-duty environment. It was for reasons such as these, and their associated cost impacts, that EPA chose not to propose a three-way catalyst based standard for HDGEs in the proposal.

If done, application of three-way systems would involve increased initial vehicle cost. However, fuel economy and performance should improve beyond current levels, as indicated in Section II above for LDGTs. Otherwise, no substantial adverse impact on fuel economy, performance or driveability is expected, due to the substantial leadtime involved and the hardware modifications available. Thus, a manufacturer would only be expected to apply three-way catalysts if it resulted in a net cost-benefit improvement with respect to its profits and consumer satisfaction.

C. Conclusions

The following conclusions result from the preceeding analysis of the comments provided on the technological feasibility of the proposed standards and from the draft regulatory analysis performed in support of this rulemaking.

A NOx standard of 6.0 g/BHP-hr should be feasible for 1988 model year heavy-duty gasoline engines. Roughly one-third of all HDGEs are already in compliance with this standard without any hardware modifications from their higher NOx counterparts. One-half of the remainder will require only increased EGR rates and engine recalibration to comply. The other half will require hardware modifications in addition to increased EGR and recalibration. Complying with a 6.0 g/BHP-hr standard should not result in undue fuel economy, performance, or driveability penalties for HDGEs.

A NOx standard of 5.0 g/BHP-hr should be feasible for 1991 model year heavy-duty gasoline engines. Roughly 15 percent of current HDGEs are already in compliance with this standard without any hardware modifications from their higher NOx counterparts. Assuming that NOx averaging will be available, roughly two-thirds of the remainder will require only increased EGR rates and engine recalibration to comply. The other one-third will require minor hardware modifications in addition to increased EGR and recalibration. This increased application of control technology should avoid any measurable performance or fuel economy penalties at the 5.0 g/BHP-hr standard level.

IV. Heavy-Duty Diesel Engines (HDDEs)

In developing the proposed emission standards for HDDEs, the NPRM analysis[1] treated the process in two distinct stages. In the first stage, the focus was on the identification of achievable emission levels for NOx and particulate emissions in the near-term (1987). In the second stage, the focus was on levels achievable in the mid-term (1990). The second stage of the development process included the evaluation of feasible engine-out NOx and particulate emission levels as well as the feasibility of trap technology. The identification of feasible engine-out NOx and particulate levels are clearly related; consequently, they are discussed together and the analysis of trap feasibility and associated particulate standard levels is treated separately. Thus, the near-term NOx and particulate standards are examined first, followed by the mid-term NOx and non-trap particulate standards and then the trap-based particulate standards.

A. Synopsis of NPRM Analysis

1. Near-Term NOx and Particulate Standards

The NPRM draft regulatory analysis[1] of the technological feasibility of the proposed 1987 NOx and particulate standards, 6.0 g/BHP-hr NOx and 0.60 g/BHP-hr particulate, consisted of five steps and is summarized as follows. The first step was the identification of NOx and particulate emission levels from current engines. These data were broken down by HDDE subclass (light (LHDDE), medium (MHDDE), and heavy (HHDDE)), because of the technological differences in engine designs between these subclasses. NOx emission levels were obtained from both Federal and California certification data. However, as particulate emissions are not currently regulated, these data had to be gathered from a variety of sources.

The second step in the analysis was the determination of the low mileage emission targets and the amount of emission reduction necessary for compliance with the proposed standards. The identification of the target level was performed according to the same basic methodology described above for LDTs and HDGEs. With respect to the amount of emission reduction required, HDDEs were divided into two groups: indirect injection (IDI) and direct injection (DI) engines. In the case of IDI engines, (engines manufactured by GM and IH), it was concluded that available transient test data on the GM engine showed that it could already comply with the proposed standards. Steady state data on the IH engine strongly suggested that it also could comply. As for the DI engines, which constitute the majority of the HDDE families, all exhibited higher NOx and particulate levels than was the case for the IDI engines. Substantial differences between various DI engine configurations were identified (naturally aspirated, turbocharged or turbocharged with aftercooling).

The third step in the HDDE analysis on engine-out emissions was the identification of the technologies which could provide the necessary emission reduction necessary for compliance with the proposed standards. The analysis for LHDDEs (roughly equivalent to IDI engines) was fairly straightforward, since the available data indicated that these engines were already at or below the 1987 standards. The MHDDE and HHDDE (roughly equivalent to DI engines) analysis was more complex and began with an estimation of short-term BSFC improvements, since reductions in fuel burned translate directly to reductions in NOx and particulate emissions. The analysis then moved on to an assessment of the effectiveness of various techniques to directly control NOx and particulate emissions, including injection timing retard and aftercooling. On the basis of the wide variation in engine design configurations present and the disparity in emissions, it appeared that each manufacturer, for each of its engines, could adopt multiple emission control strategies for compliance with emission standards.

The fourth step was an assessment of the effect of the proposed 1987 standards on HC emissions and fuel economy. In estimating the fuel economy effects of the proposed standards, EPA considered estimates provided by manufacturers as well as estimates developed by the National Academy of Sciences (NAS) (page 2-76 in Reference 1). The resulting estimated effect on fuel economy was for up to a two percent reduction initially diminishing to zero by the third year of the proposed standards (6.0/0.60).

Leadtime was the final step. Since the emission control strategies expected to be used in complying with the proposed standards involved recalibrations of injection timing, modification of aftercooling and/or the addition of aftercooling on some engines, the leadtime required for the implementation of the proposed standards was considered to be within the time proposed for implementation.

2. Mid-Term NOx and Non-Trap Particulate Standards

In the NPRM analysis, the assessment of the feasibility of the 1990 NOx and non-trap particulate standards was performed in three steps and is reviewed as follows. The initial step of the 1987 analysis, the determination of current emission levels, did not have to be repeated, since it could be assumed that all engines would be at the design targets necessary to meet the 1987 standard. Thus, the first step developed the target levels for the proposed 4.0/0.40 standards; the same methodology as had been employed for the 6.0/0.60 proposed standards was used. The target levels developed were 3.2-3.6 g/BHP-hr NOx and 0.30-0.33 g/BHP-hr particulate.

Next the analysis assessed the effectiveness of various control techniques. Technologies projected to be required for compliance with 4.0/0.40 engine-out emissions standards were broader than those anticipated for the 6.0/0.60 proposed standards and included the following; additional injection timing retard, advanced aftercooling designs, improved combustion chambers, high pressure fuel injection, exhaust gas recirculation, electronic controls, in-cylinder heat retention and fuel modification. In light of the wide variation which exists between specific diesel engines, it was anticipated that manufacturers would, on an engine specific basis, select the combinations of these technologies most appropriate for each engine.

Finally in the third step, the effect of the proposed standards on fuel economy was examined. In the short term, i.e. immediately following the effective date of the proposed standards, the projected effects of the 4.0/0.40 proposed standards on fuel economy was for a 1-2 percent penalty which should be eliminated with time.

3. Trap-Based Particulate Standards

In the NPRM analysis[1] of the feasibility of particulate trap-oxidizers for heavy-duty diesel use, EPA determined that traps would be feasible for 1990 model year HDDEs. Due to the limited amount of available HD trap development data, the analysis first examined light-duty trap status and then considered the degree of additional development effort required by the heavy-duty industry. As a result of this and the ongoing research and development data, EPA concluded that trap-oxidizers would be available to permit compliance with a HDDE trap-based particulate standard; the standard level was also calculated in this analysis. The following will synopsize the four steps of the NPRM analysis: LD trap status; LD/HD differences; HDD trap status; and emission levels.

Based on past EPA analyses and a contracted study[3,4,5], the Agency concluded that light-duty trap technology was at a very advanced stage of development and light-duty trap oxidizers would be technically feasible no later than the 1987 model year. The findings that traps were feasible for 1987 model year LDVs was also based on Daimler-Benz's plans to certify a trap-equipped vehicle to meet California's 1985 emission standards. Although there were still unresolved problems associated with some trap systems (e.g., introduction of a fuel additive to the fuel to induce regeneration, the development of a fully automated positive regeneration system, and the occurrence of increased sulfate emissions from catalyzed traps), EPA believed that the other manufacturers were not far behind Daimler-Benz's trap development and compliance was possible for 1987 LDV use.

The second step in the analysis examined the applicability of light-duty trap technology to heavy-duty engines, concluding that there was nothing preventing the adaptation of light-duty technology, with additional development, to heavy-duty usage. The further advanced light-duty trap technology formed the basis for the development of similar technology for the heavy-duty diesel engine industry. However, conditions specific to the HDDE environment were identified which must be considered in the design of heavy-duty trap oxidizers. The major light-duty/heavy-duty differences included: engine size and load factor; operating conditions and temperatures; the useful life of the engine; and ash accumulation. Although considerable development effort was found to be required of the heavy-duty industry in the adaptation of light-duty trap technology for heavy-duty use, EPA did not consider the problems to be without engineering solutions.

The analysis continued with a survey of the ongoing heavy-duty trap research and development. The Agency found a definite lack of data from the HDDE industry, noting the difference between LD trap progress, where the LD industry has had to work towards a trap-based standard, and HD trap progress, where the HD industry has not had that incentive. The limited development work was primarily focused on trap regeneration and its control. (Trap type, for the most part a direct derivative of light-duty design, was not considered a major obstacle, although some design effort in this area remained). Regeneration methods being evaluated included, but were not limited to, burners, fuel additives and catalyzed traps. Development of an automatic regeneration control system appeared to be the next major step. EPA realized that traps were not at the time a viable particulate control, but the Agency firmly believed that, with industry's vigorous pursuit of a trap-oxidizer system, traps would be achievable for HDDEs by 1990.

The final step identified a feasible standard for trap-equipped heavy-duty diesel engines. The proposed trap standard was dependent on the following factors: the engine-out design target level, the deterioration factor (DF), the SEA adjustment factor and the trap efficiency. The target level, SEA adjustment factor and DF for the engine-out emission level of 0.60 g/BHP-hr were determined in the non-trap standard section of the analysis. The 1.0 DF for traps was based on LDD particulate emission tests of over 50,000 miles that resulted in no significant deterioration. The final and most variable factor, the trap efficiency, ranged from 50 to greater than 90 percent, dependent on trap type. The Agency determined that with 80 percent efficient traps, HDDEs could comply with a 0.25 g/BHP-hr standard; with averaging, approximately 70 percent of the HDDEs would require traps. If essentially all vehicles are equipped with 90 percent efficient traps then a 0.10 g/BHP-hr standard was determined to be feasible.

The technology feasibility analysis concluded that there appeared to be sufficient time for the manufacturers to design, develop, and prepare trap-oxidizers for 1990 model year HDDEs. This followed from the fact that traps will be in production on many light-duty diesels no later than 1987. The five years of leadtime between mid-1984 and late 1989 were found to allow adequate time for the additional design effort required for HDDE modifications.

B. Summary and Analysis of Comments

1. Near-Term NOx and Particulate Standards

The proposed 6.0/0.60 standards for 1987 represented an attempt by EPA to obtain meaningful, yet balanced, reductions in both NOx and particulate in the near term. For example, greater NOx reduction could have been proposed. California already has a 5.1 g/BHP-hr NOx standard for HDDEs. However, California has no particulate standard for HDDEs and particulate levels almost certainly average well above 0.60 g/BHP-hr. Since EPA also desired to establish near-term particulate control, NOx controls were proposed only to the point where they did not unduly impact potential near-term particulate control levels.

Though always intertwined, the issues of feasibility and leadtime are more separate here than in many other cases, due to the fact that the 6.0/0.60 standards were proposed to take effect in a very short period of time, just over two years from the date of proposal. Thus, those issues related primarily to feasibility will be discussed first followed by those concerned primarily with leadtime.

a. Feasibility

Overall, the 6.0/0.60 standards were fairly well received by manufacturers. A number of manufacturers indicated that they were feasible for either 1987 or 1988. Most manufacturers, however, took issue with the details of EPA's analysis in support of the standards. Thus, these details need to be addressed, as well as overall comments with respect to feasibility and leadtime.

These details fall into three basic categories. The first is the identification of the design goal, or target, associated with the two standards. The second deals with the projected effectiveness of control technology and the ability to reach the design targets. The third deals with the effect of these technologies on BSFC, or fuel economy.

i. Design Targets

Design targets are a function of: 1) the emission standard, 2) the DF applicable over the full useful life, and 3) emission measurement variability. The model, or equation, used to determine a low-mileage target based on these parameters is well known and accepted. The only issue relating to the model itself is the assumption that the emission variability of an engine is known sufficiently well to allow use of the z-statistic as an indication of the statistical effect of this variability as opposed to the K-statistic. Therefore, differences in estimated design targets arise due to the use of different input DFs and emission variabilities or the use of the K-statistic rather than the z-statistic.

A substantial amount of comment was provided on the development of the target levels necessary for compliance with the proposed 1987 standards. Six commenters provided numerical value comments on the low mileage emission target levels necessary for compliance with the proposed NOx and particulate standards of 6.0 g/BHP-hr and 0.60 g/BHP-hr, respectively. The target levels provided by the commenters are shown below:

	Low mileage Target Level (g/BHP-hr)	
Commenter	NOx	Particulate
Draft RIA	5.1-5.5	0.47-0.51
Cummins	5.25	0.42 (assumes improved knowledge)
EMA	4.94-light heavy 4.90-medium heavy 4.84-heavy heavy	0.35-light heavy 0.29-medium heavy 0.21-heavy heavy
Ford	---	0.32-0.47-medium heavy*
GM	4.5 to 4.9**	0.32 to 0.37**
International Harvester	4.88-light heavy 4.84-medium heavy	0.36-light heavy 0.30-medium heavy
Mack	5.45 for production variability	0.47 (0.05% sulfur in fuel)

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* Depending on assumptions on DFs and variability.

** Target levels may be increased as more knowledge is gained.

The low mileage NOx target level was estimated in the Draft RIA to be 5.1 to 5.5 g/BHP-hr, based on a coefficient of variation (COV) for NOx and particulate of 10 and 10-15 percent respectively, and full-life DFs of 0-0.48 g/BHP-hr NOx and 0.04-0.06 g/BHP-hr particulate and use of the z-statistic. Neither Cummins nor Mack provided details on the methodology used in developing their target level estimates, so their estimates cannot be technically evaluated. However, both estimates are inside the range identified by the Draft RIA, at least for NOx, so their estimates of the NOx DFs and COVs must be close to those of the Draft RIA.

The EMA, GM and IHC estimates were based on use of the K-statistic to account for emission variability, which assumes that the standard deviation of NOx emissions for a given engine family is unknown. As discussed in the Draft RIA, the more appropriate statistic is the z-statistic, since fairly accurate estimates of the standard deviation will be available prior to production decisions for 1988. For example, as evidenced by Cummins' comments, manufacturers are already testing their production audit engines for particulate. No new information was received which justified changing this conclusion.

The DFs used by EMA and IHC were derived from in-use engine data from two sources: 1) an EEA study (performed for EPA) of vehicle testing performed at SwRI and 2) engine testing from the joint EPA-EMA in-use test program. A linear regression was performed on the after-maintenance data (or as-received if maintenance was not performed) from these two programs vs. mileage to derive DFs for NOx and particulate. The resulting NOx DFs were not far from those estimated in the Draft RIA, but the particulate DFs were substantially larger.

Generally, such regressions are performed to derive estimates of average in-use emissions. This was the purpose of the EEA study sponsored by EPA. Included in the results of such a study is an estimate of how fleet-average emissions change with mileage (i.e., an in-use average DF). However, unless the engines or vehicles tested meet the criteria for inclusion in a recall action, the resulting DFs are not appropriate for use in a design target analysis.

An analysis of the engines included in these two programs shows their condition to be far from satisfactory for recall evaluation. Many were tampered and restorative maintenance was performed on only 13 of 48 engines. Thus, the resulting DFs essentially represent in-use DFs and not those of well-maintained engines and should not be used here.

The GM DF for NOx was estimated from a subset of the data referenced by EMA and IHC. However, even given this fact, it fell into the range of the Draft RIA. GM's DF for particulate was simply estimated to be 0.15 g/BHP-hr. This is well outside the range used in the Draft RIA, but cannot be evaluated since its basis is not known.

The Draft RIA NOx DFs were based on 1984 half-life data; doubled to represent full-life DFs. Full-life 1985 data are now available and are shown in Table 2-10. Only the manufacturer-developed DFs are shown, since they are based on actual durability testing. Assigned DFs are provided by EPA at the manufacturers choice, but these are worst-case estimates to encourage actual durability testing. Overall, half of the developed DFs are zero and only three are significantly more than the upper estimate used in the Draft RIA (0.48 g/BHP-hr). The average developed DF in each subclass is 0.0 (LHDDE), 0.1 (MHDDE) and 0.32 g/BHP-hr (HHDDE). Thus, the range of the Draft RIA appears somewhat conservative for LHDDEs and MHDDEs. Since quite a few HHDDE DFs are quite near 0.48 g/BHP-hr, the Draft RIA upper limit appears quite appropriate for these engines. It should be noted that manufacturers currently have little pressure to reduce NOx DFs since the 10.7 g/BHP-hr standard is well above low-mileage emission levels. Thus, current DFs, particularly the largest, could very well represent conservative estimates of future DFs when they become a factor with respect to compliance.

Lacking data, the Draft RIA assumed the DF for particulate emissions would be similar to the NOx or HC deterioration factors when expressed as a percentage of the emission level. Commenters contended that normal wear in such components as the fuel injection pump, its controls, injectors and piston rings would be expected to cause an increase in HC and/or particulate emissions while causing a decrease in NOx emissions. Given the fact that most NOx DFs are zero or negative and this would not be expected for particulate, the use of HC DFs as a surrogate is probably more appropriate. Referring to Table 2-11, for LHDDES, the ratio of the mean deterioration factor to the mean low mileage emission level was found to be 0.14. Corresponding ratios for MHDDEs and HHDDEs were found to be 0.05 and 0.06, respectively. Under a particulate standard of 0.60 g/BHP-hr, the low mileage level will be roughly 0.5 g/BHP-hr and the preceding ratios developed from actual HC deterioration factors would correspond to particulate deterioration factors of 0.07, 0.025, and 0.03 g/BHP-hr for light, medium and heavy HDDEs, respectively. These values bracket very closely the DF range (.04 to .06 g/BHP-hr) developed in the Draft RIA. Thus, this range continues to appear appropriate.

Table 2-10

1985 Federal Full-life Deterioration Factors

	DF (g/BHP-hr)[1]
LHDDE	
GM	0.0
IHC	0.0
MHDDE	
GM	0.0, 0.0
Caterpillar	0.02
IHC	0.0, 0.0, 0.61
HHDDE	
GM	0.65, 1.14
Caterpillar	0.0, 0.0, 0.47
Cummins	0.07, 0.39, 0.46, 0.46
Mack	0.00, 0.00, 0.00, 0.37
Volvo White	0.50

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* Only manufacturer-developed DFs are shown. Assigned DFs are essentially worst-case DFs and are not necessarily indicative of an engines actual DF.

Table 2-11

1985 Model Year HDDE HC Emission Levels and Deterioration Factors Developed by Manufacturers

Manufacturer	HC DF	HC Low-Mileage Emissions
LHDDE		
General Motors	0.15	0.53,0.46
International Harvester	0.00	0.79
MHDDE		
Caterpillar	0.06	0.62
General Motors	0.05,0.00	0.58,0.84
International Harvester	0.00,0.08,0.03	0.70,0.85,1.32
HHDDE		
Caterpillar	0.00,0.21,0.01	0.19,0.36,0.32
Cummins	0.00,0.00,0.00,0.02	0.46,0.62,0.92,0.52
General Motors	0.00,0.00	0.48,0.54
Mack	0.19,0.00,0.00,0.00	0.90,0.69,0.74,0.54
Volvo White	0.10	0.81,1.15

With respect to the last pertinent factor, emissions variability, EMA, IHC, and GM all used estimates which included lab-to-lab variability. This would be appropriate in an analysis focused on pre-production certification requirements, if EPA were to perform confirmatory tests at its own lab. However, the focus here is SEA, because its requirements are statistically more stringent than those of certification. SEAs are performed at manufacturers' own facilities. Thus, any differences between a manufacturers' own labs are well known and characterized. Thus, inclusion of lab-to-lab variability, particularly insofar as these estimates were based on the variability among seven independent test facilities, is not appropriate here. When this is taken into account, the estimates of EMA, IHC, and GM would be very similar to those of the Draft RIA.

Overall, then, the inputs parameters estimated in the Draft RIA still appear appropriate. Thus, the design targets remain unchanged at 5.1-5.5 g/BHP-hr NOx and 0.47-0.51 g/BHP-hr particulate. However, the fact that most manufacturers' estimated design targets were well below these levels should be kept in mind below as control technology effectiveness is discussed. An unrealistically low design target overestimates the degree of control necessary to achieve a standard. Therefore, either the necessary application of technologies is overestimated, or a standard is termed infeasible when it is not.

ii. Control Technology Assessment

The analysis of HDDE control technology is inherently difficult, because each manufacturers' engines are designed somewhat differently and have varying technical capabilities. Differences between the generic HDDE subclasses compounds this task. Thus, engine-specific analyses are not possible due to the complexity of the task. However, even if such an attempt were possible, the necessary data are not available in most cases. Thus, the analysis in the Draft RIA and that performed here must address generic control techniques and reduction capabilities, while at the same time considering differences between engine designs insofar as possible.

Another factor adding to the complexity of the task is the rapid change in technology currently affecting HDDEs. New technologies, such as enhanced aftercooling, variable injection timing, electronic engine controls (EEC), higher-pressure injection and higher efficiency, faster response turbochargers are all being introduced to some degree to improve BSFC, regardless of emission levels. However, many of these technologies also directly effect NOx and particulate and are among those considered below as potential control technologies. A problem is that all of these can be optimized for BSFC or emissions and interact in a complex way. Thus, it is also difficult to determine a pre-control baseline. The result is that future technology must be estimated both with and without these standards and data from engines encompassing a representative sample of these technologies must be relied upon to estimate overall control effectiveness. While important here, these factors are even more dominant in the analysis of the 4.0/0.40 standards to follow.

Unfortunately, little data were received in comments on the 1987 standards which quantified the effect of the various control techniques projected to be both available and effective in achieving these standards in the Draft RIA. Most commenters simply stated whether or not the 6.0/0.60 standards were feasible and, if so, when. Some also presented their qualitative judgment of EPA's feasibility analysis. A few (e.g., GM) presented charts of NOx/particulate and NOx/BSFC curves for each of their engines. However, without test data and descriptions, these also cannot be properly evaluated. Manufacturers' comments pertaining to overall feasibility will be summarized first, followed by general comments, pertaining to the Draft RIA analysis. These comments will then be analyzed using what data were supplied, as well as those included in the Draft RIA.

Daimler-Benz stated, without qualification, that their MHDDEs could achieve compliance with the proposed standards in 1987, as did Volvo White with respect to 1988. Ford also stated that compliance with the proposed 1987 standards was achievable, but indicated this conclusion was based on projections that both DFs and emission variability would be relatively low (which they expected and which appeared reasonable given the analysis presented above). GM indicated that its medium- and heavy-HDDEs could also comply in 1987, but with some fuel economy penalty (which is addressed below). In the case of its light heavy-duty engine, GM indicated that compliance with both the proposed particulate and NOx standards was not achievable simultaneously.

Comments by the other manufacturers as well as by EMA did not include direct statements on either an anticipated ability to comply nor an anticipated inability to comply. However, the comments did include discussions of the technologies required for compliance and the time required for implementation. Thus, it is reasonable to infer that compliance with the proposed standards was considered to be technically achievable by these other manufacturers, as well. Cummins and Mack did mention implementation years of 1989 and 1990 respectively, for at least the NOx standard. However, leadtime will be considered further below.

Overall, the only manufacturer to absolutely question the feasibility of the 6.0/0.60 standards was GM for its LHDDEs. On the surface, this is rather surprising since data generated in EPA's Ann Arbor Lab on a low-NOx version of this engine (referenced in the Draft RIA) showed it to have the lowest combination of NOx and particulate emissions of any engine (3.0 NOx and 0.46 particulate, g/BHP-hr). Also, prototype data submitted by GM after the original proposal (then confidential, but recently made public in an EPA-sponsored study[6]) show emissions to be 4.1 NOx/0.46 particulate and 2.8 NOx/0.52 particulate at two calibrations (all in g/BHP-hr). While the levels of 1984 production engines are somewhat higher (4.2 NOx/0.66 particulate and 3.6 NOx/0.62 particulate, respectively), these levels are still low relative to those of the other engines and no incentive existed in 1984 to keep either NOx or particulate as low as the prototype levels.

GM did not refer to any of these data, but did present a NOx/particulate trade-off curve for this engine. The curve is slightly below the 1984 production data, but well below prototype curve. No explanation is given concerning the prototype/production difference. Also, GM's estimated design target for the particulate standard is 0.32-0.36 g/BHP-hr, which is below even the prototype data and may explain GM's conclusion. It should not be necessary, based on EPA estimates, to design an engine below a design target of 0.47-0.51 g/BHP-hr particulate, as discussed above. Consequently, this engine must be considered capable of complying with the proposed standards.

Moving on to comments on the Draft RIA analysis, a number of manufacturers (Caterpillar, in particular) indicated that some of the analyses were rather simplistic and not realistic. For example, Caterpillar took issue with EPA's statement that California's 5.1 g/BHP-hr NOx standard could easily be met with simple injection timing retard. Caterpillar also disagreed with EPA's implication that transient particulate emissions can be reduced to steady-state levels, through improved transient fuel rate control.

With respect to the first statement, Caterpillar took the statement more literally than intended. The primary point being made was that, with respect to techniques designed primarily to control NOx control techniques, injection timing was sufficient (i.e., no other NOx control techniques were required) and the point was not that absolutely no other changes (e.g., recalibrations) would be required. Caterpillar lists a number of changes made to its California engines in addition to injection timing retard, such as power de-rate, turbocharger modifications, and fuel governing modifications. These are reasonable recalibrations whenever a basic engine parameter, such as injection timing, is changed. However, they in themselves are not necessarily NOx control techniques, though their cost must be considered.

With respect to the second statement, Caterpillar's judgment is based on a belief that advances in turbocharger design have already achieved most of what is to be gained in improved transient response. Further, they claimed that over-fueling is necessary to accelerate an engine. Again, the point being made in the Draft RIA was not that the entire transient/steady-state difference could be eliminated, but that improvements were possible and the current transient/steady-state difference was an indication of this potential. Given the work known to be underway by both turbocharger manufacturers and other HDDE manufacturers--evidenced by the numerous technical papers in the area even though most of what is being done is proprietary--it does not appear reasonable to conclude that turbocharger response cannot be measurably improved. Also, the potential capability of electronics to precisely limit fuel delivery to minimize any particulate control/performance could also be substantial. Whether such improvements can be achieved by the 1987-1988 timeframe fleet-wide is another issue.

Each manufacturer also identified, in varying degrees of detail, the technologies which it expected to use on one or more of its engines to achieve compliance with the proposed 6.0/0.60 standards. The technologies identified were as follows: 1) application of turbocharging, 2) turbocharger modifications, such as improved efficiency and transient response, 3) addition of aftercooling to turbocharged engines, 4) enhanced aftercooling), 5) injection timing retard, 6) addition of variable injection timing, 7) increased fuel injection pressure, 8) fuel injector modifications, and 9) modifications to the combustion chamber and air swirl rate. Manufacturers also indicated that they anticipated an ongoing introduction of electronic controls focused mainly on the minimization of fuel economy penalties.

These technologies are basically the same as those projected in the Draft RIA for both the 1987 and 1990 standards. While some use of the technologies associated with the latter standard was anticipated in 1987, manufacturers appear to be utilizing a greater number of combinations of technologies at the 6.0/0.60 level than had been projected in the Draft RIA, possibly because of fuel economy concerns.

Telephone communications with manufacturers concerning their 1985 model year California engines showed that combinations of the technologies listed above are in use on these engines. However, since the half-life California NOx standard is essentially equivalent to a 5.1-5.35 g/BHP-hr full-life standard, it is 0.65-0.9 g/BHP-hr more stringent than the proposed Federal standard and not all of these technology modification/additives (at least these which are NOx related) should be required to comply with the 6.0/0.60 standards.

With respect to the NOx standard, EPA acknowledges that sole reliance on injection timing retard to achieve compliance in the 6.0 g/BHP-hr NOx standard could result in significant fuel penalties. Thus, to minimize fuel penalties manufacturers may elect to increase the use of aftercooling and variable injection timing. However, the use of enhanced aftercooling, particularly air-to-air units, appears more appropriate at NOx levels more stringent than 6.0 g/BHP-hr, it should not be necessary at 6.0 g/BHP-hr NOx. If air-to-air aftercooling were applied, it would be to reduce BSFC and should not be included as a cost of the 6.0 g/BHP-hr standard.

With respect to particulate emissions, some additional use of turbocharging was projected in the Draft RIA, particularly with respect to Caterpillar's 3208 engines. This was confirmed by Caterpillar in their comments. Also, the Draft RIA identified the general need for modifications to existing engine components, but none involving additional hardware. These components include modified injectors and combustion chambers, improved fuel governing during transients, and moderate increases in injection pressure, all of which are described in more detail in the Draft RIA.

Due to the difficulties mentioned above, such as heterogeneous engine designs, lack of engine-specific data and rapidly changing technology to reduce BSFC, specific estimates of the technological changes necessary for each engine cannot be made. However, most of the changes described above primarily involve research, development and tooling. The revised components should inherently be no more expensive in the long-run than the original components. Thus, the cost of these standards may not depend strongly on the number of changes made, but rather on the need to perform the necessary research and development to determine which changes actually need to be made. For the most part, much of this research has been ongoing already or performed.

iii. HC and Fuel Economy Effects

No technically supportable comments were received indicating the 1988 standards would significantly increase HC emissions. However, comments pertaining to the fuel economy effects of the proposed standards were provided by most commenters. The estimated fuel economy penalty anticipated by each commenter are shown below together with the basis for the estimate, when one was provided.

Commenter	Fuel Economy Penalty
Caterpillar	3-12 percent (1985 Federal/ California difference)
Cummins	1-3.5 percent
GM	3-5 percent for MHDDE 4-6 percent for HHDDE 2 percent for new design HHDDE
International Harvester	4-8 percent from NAS study 5.4-7.2 percent MHDDE 7.7-8.3 percent HHDE (1985 Federal/California difference)
Mack	6 percent (1985 Federal/ California difference is 4.7-12.5 percent)
Daimler-Benz	No significant loss in fuel economy

Many of the manufacturers' projections on reduced efficiency of fuel utilization were based on differences between 1985 model year Federal and California engines. This is not an appropriate comparison since the California standard is 5.1, not 6.0 g/BHP-hr and the California engines are 1985 models, not 1988. The California standard is a full-life standard, but does not include an assembly line test program. This allows a somewhat smaller safety margin, since SEA is generally considered to be statistically more stringent than certification. However, this difference should be only a small part of the 0.5 g/BHP-hr margin attributable to SEA. Thus, the California program can be considered to be essentially on par with the Federal program at equal standard levels. As the 5.1 g/BHP-hr NOx standard is much closer to 5.0 rather than 6.0 g/BHP-hr, the California data are more useful in assessing the fuel economy effect of the 5.0 g/BHP-hr standard than this one.

IHC made an additional comment that the NAS study was not based on "old" technology, as concluded in the Draft RIA, but on advanced engine technology, at least insofar as the data IHC supplied. Whether or not this is true for other manufacturers' data cannot be determined, since no other comments were received on this point. However, even if some of the data were from advanced technology engines, the absolute NOx and BSFC levels of the NAS curve and the resulting trade-off make it apparent that any advanced technology was applied to optimize BSFC and power and not NOx control. This approach is not consistent with the approach taken in estimating the economic impact of this rule (see Chapter 3), where the cost of advanced technology is being charged to NOx control. Given this, any fuel penalty should be determined from the BSFC of the engine without the advanced technology, not with it. Also, the nature of the NAS study made it impossible to cite the specific data used to derive their NOx/BSFC curves. Therefore, it cannot be determined how much optimization of BSFC occurred at low NOx levels. Thus, the NAS BSFC/NOx curve still appears to overestimate the effect of NOx control.

There is another reason why some of the manufacturers' estimates shown above may overestimate the fuel economy penalty of the 6.0 g/BHP-hr standard. That is the fact that at least GM and IHC used a low-mileage NOx design target 0.6 g/BHP-hr lower than that necessary. Use of a 5.1-5.5 g/BHP-hr target would result in lower estimated fuel penalties. This appears to be confirmed by Cummins estimate. Cummins' estimated a NOx design target with the above range and also projected the lowest fuel economy penalty of any manufacturer, except Daimler-Benz.

While 1985 California BSFC penalties cannot be directly applied to the 6.0 g/BHP-hr standard, they can be used indirectly to confirm the 0-2 percent estimate of the NPRM. These differences between the California and Federal situation need to be considered. One, an additional three years of leadtime will be available allowing additional control system optimization . Two, the low-mileage targets will be 0.9 g/BHP-hr NOx higher so less NOx control will be required, lowering any fuel penalty. Three, the technologies being used in California are primarily quick fixes, requiring low initial capital investment (research, development, soiling). Given the longer leadtime available and the fact that nationwide sales will be effected by high BSFC, and not just California sales, much more comprehensive research and development, resulting in optimized control approaches and lower BSFC penalties, should result even with today's technology. Thus, the upper end of the current California penalties must be considered extreme under these conditions. The lower end of the penalties, 3-4 percent, should also be able to be lowered, given the additional leadtime and added return for the same investment (i.e., Federal vs. California sales). Thus on average in the short term, a maximum penalty of 2 percent may result from the 6.0/0.60 standards. The possibility of no penalty also exists given Daimler-Benz' comment. Thus, in the short term, the average fuel economy penalty should be 0-2 percent.

In the long run, beyond 1988, one would expect the penalty to disappear altogether. This is because the advanced technology projected in the 1991 timeframe should improve fuel economy such that any short-term penalty will be eliminated by the early 1990's. Also, general improvements in BSFC will lower fuel consumption over the emissions test cycle and, other things being equal, NOx and particulate will decrease as well.

It was estimated in the Draft RIA that BSFC would decrease roughly 1.5 percent per year in this timeframe based on comments from MVMA and EMA to the MOBILE3 development process confirm this figure. Thus, three additional years should provide a 4-5 percent reduction in NOx emissions simply due to BSFC improvements.

b. Leadtime

The issue of the amount of necessary leadtime associated with the 6.0/0.60 standards received a substantial comment. This analysis will begin by describing the steps necessary in developing engines and vehicles to meet emission standards, along with the time associated with each step. The comments to the 1987 implementation date will then be summarized, followed by an analysis of those comments.

All work necessary for emissions compliance by the engines does not have to be completed prior to initiation of design work for engine integration into the vehicles, but sufficient progress has to be made in engine development so as to clearly define the engine envelope (overall spatial requirements of the engine, including aftercooling). The primary tasks involved in the successful development and marketing of engines complying with the 6.0/0.60 g/BHP-hr standards in vehicles are shown in Table 2-12.

The total leadtime requirement for engine development is the sum of tasks A through H less task C, or 31-38 months. Since the standards are applicable to all HDDEs, the greater of the two time requirements for durability data development was used. In the case of vehicle development, the leadtime required is the sum of tasks A, B, C, I, J, and K, or a total of 28-36 months.

Starting with a March 15, 1985 date for publication of the final rule, the time available for implementation of new standards by the 1987 model year (January 1, 1987) would be approximately 21 months. The time available for implementation of new standards by the 1988 model year (January 1, 1988) would be approximately 33 months. Since the time available for implementation by the 1987 model year is significantly less

Table 2-12

Leadtime Projection - 6.0/0.6 Standards

	Task	Time Required
A.	Identify, by engine, technologies probably required for compliance, develop initial designs	3-4 months
B.	Procure initial design hardware, build and test initial design test engines	4-6 months
C.	Develop engine envelope requirements for vehicle builders	1-2 months
D.	Develop second level engine designs	2-3 months
E.	Procure hardware, build engines with alternative calibrations and develop emission data and fuel economy characteristics by calibration to define durability engine calibrations	8-9 months
F.	Develop emission durability data	4-5 months for light-heavy 11-12 months for heavy-heavy
G.	Develop data from emission data engine	1 month
H.	Coordinate emissions certification compliance with EPA	2-3 months
I.	Develop overall vehicle design considering the effects of all engines offered in each vehicle	8-10 months
J.	Procure new dies for the manufacturer of redesigned vehicle components	7-9 months*
K.	Confirm mechanical durability of redesigned vehicle components	5 months**

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* Reference 2.

** 60,000 miles at 40 mph average speed, two effective 7-hour shifts per day and six days per week.

than even the minimum time estimated above, implementation in the 1987 model year does not appear feasible for most engines. The time available prior to the 1988 model year is within the range of estimated time required. Also, the entire process can be accelerated in those extreme cases where more time is necessary. Thus, 1987 should be ruled out on the basis of inadequate leadtime for industry-wide compliance; however, the 1988 model year appears feasible.

Moving to the comments, one commenter, Daimler-Benz, stated that their engines could be brought into compliance with the proposed standards for the 1987 model year. GM stated that all but their one LHDDE could comply in 1987. However, other commenters indicated that a greater amount of time was required, usually one year, but occasionally more. Specifically, Ford and Volvo White acknowledged that 1988 was feasible while Caterpillar indicated that 1988 was the earliest date feasible. International Harvester estimated that 39 months starting from the date that the engine configuration is finalized would be necessary to allow integration of the reconfigured engine envelope into the vehicle, to accommodate changes in engine cooling requirements, the addition of air-to-air aftercooling, the addition of electronics and compliance with noise and safety standards.

Cummins and Mack requested that the standards be delayed until 1989 and 1990, respectively. Both cited the statutory mandate of 4 years leadtime, but also referred to technical difficulties. Cummins indicated generally that anything less than the statutory leadtime would require them to accelerate development of their planned engine modifications to a degree which would seriously affect the durability, reliability and fuel efficiency of their engines. Mack considered the 1990 date necessary because essentially all Mack engines had to be redeveloped and personnel limitations precluded earlier completion.

The two projections (by Daimler-Benz and GM) of 1987 as the feasible year of introduction indicates the ability to compress the schedule described in Table 2-11 above. It may also indicate that manufacturers are starting from different points (i.e., levels of current emissions).

Without emission data or specific leadtime estimates, it is impossible to evaluate the IHC, Cummins and Mack leadtime estimates, which are the only ones requesting time beyond 1988. (Cummins' and Mack's legal agreements are addressed in the Preamble to the FRM.) Generally speaking, the types of changes being referred to by IHC should not be necessary to comply with the 6.0/0.60 standards. They may be desirable in the long-run to improve BSFC, but they are not driven by the 6.0/0.60 standards.

Given the above leadtime analysis, the infeasibility of 1987 as an effective date, the general support for 1988 as a feasible year of implementation, and no clear, supported arguments by any manufacturers against it, 1988 is determined to be the year the 6.0/.60 standards should be implemented.

2. Mid-Term NOx and Non-Trap Particulate Standards

A mid-term (1990) NOx standard of 4.0 g/BHP-hr was proposed for all HDDEs. A 1990 particulate standard of 0.40 g/BHP-hr was also tentatively identified as the non-trap technological limit, and proposed as a possible standard for non-urban (line-haul) HDDEs. In identifying these levels, the same approach was used as that described above concerning development of the near-term standards. The goal was to obtain both NOx and particulate emissions, but NOx emission control was balanced so as not to severely impact the ability to control particulate emissions.

The difficulties in performing an analysis such as this, which were described with respect to the 6.0/0.60 g/BHP-hr standards above, apply even more here. While the heterogeneity of engine designs is the same, technology is changing even more dramatically in this later timeframe and the interaction between control techniques is even stronger. Also, even less data exist than was available for 1987 technology, to base feasibility judgments on.

Again, as with the 1987 standards, there are two basic issues: technical feasibility and leadtime. However, here the issues associated with leadtime are much less significant, because the implementation date is sufficiently distant to allow significant research and development application. The long leadtime available should provide manufacturers with adequate opportunity to overcome problems and undesirable effects associated with additional NOx control. Also, the proposed 1987 standards require delay until 1988 and the Act requires a three-year interval for NOx emission standards; thus, the mid-term NOx standards cannot take effect until 1991. This analysis will presume simultaneous implementation of both NOx and particulate standards since that will maximize the manufacturers' ability to design engines that can meet both standards.

a. Technical Feasibility

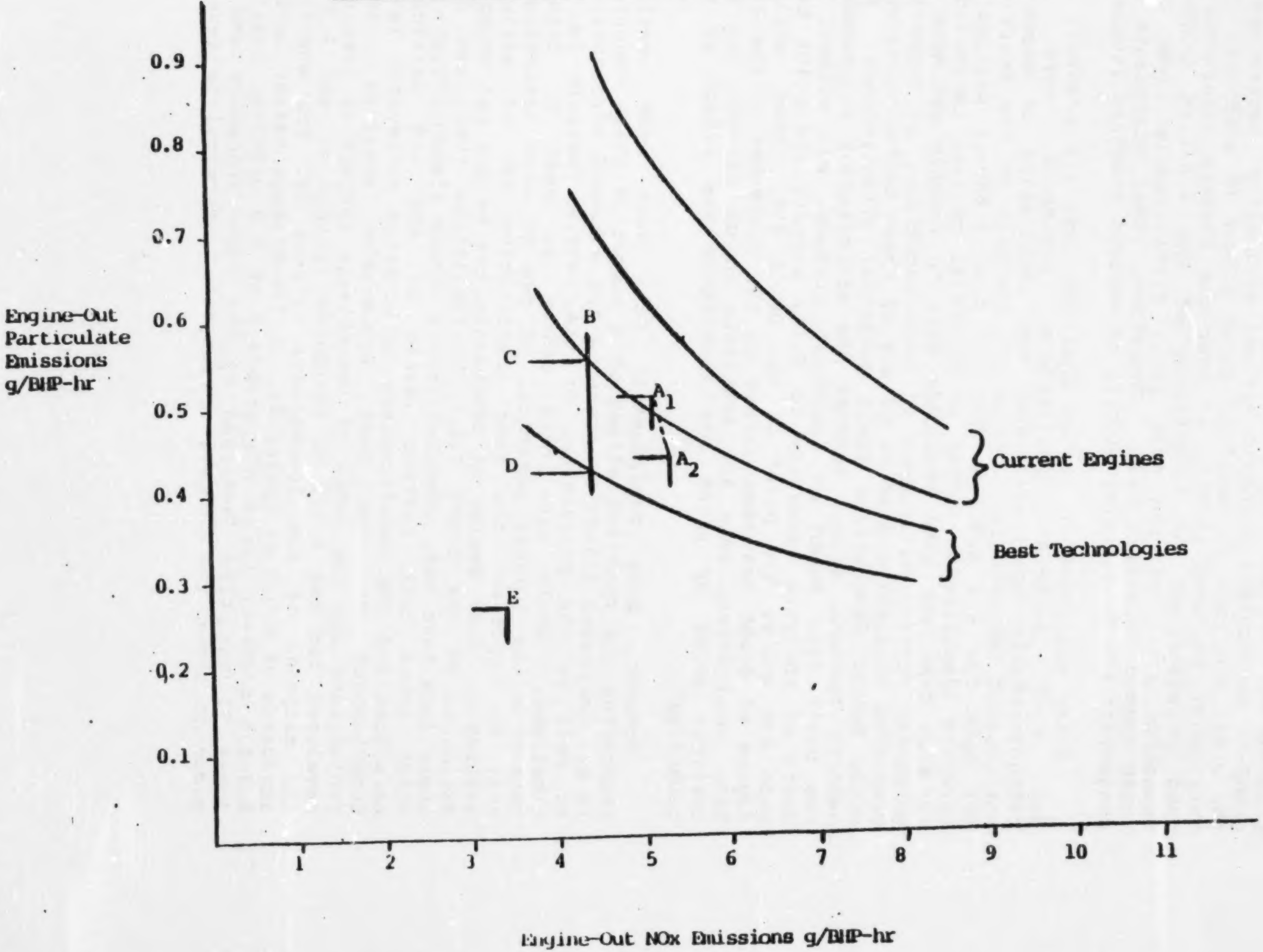
The analysis of these technical comments will follow that for the 6.0/0.60 g/BHP-hr standards. The one exception is that no reanalysis of design targets will be performed here. No new information is applicable that was not already discussed with respect to the 6.0/0.60 standards. That analysis confirmed the Draft RIA's targets. Thus, the Draft RIA NOx target of 3.2-3.6 g/BHP-hr will be used below. A target associated with the 0.40 g/BHP-hr particulate standard was not explicitly determined in the Draft RIA, but it would be about 0.30-0.33 g/BHP-hr. The only point to keep in mind is that the targets manufacturers used in assessing the feasibility of the 4.0/0.40 g/BHP-hr standards are, for the most part, significantly lower than those deemed necessary here. Therefore, their statements may exaggerate the feasibility efforts of various standard levels.

Every manufacturer stated that the 1990 4.0 g/BHP-hr NOx and 0.40 g/BHP-hr particulate standards were not technologically achievable with any combination of known or anticipated technologies. While the analysis of the Draft RIA for both the 4.0 g/BHP-hr NOx and 0.40 g/BHP-hr particulate standard identified a number of potential control technologies in each case and used available data to roughly estimate the potential control efficiency of each technique, no commenters presented parametric studies of any of these technologies which would better demonstrate their potential effectiveness. Many general comments argued against the efficiencies estimated in the Draft RIA, based on technical grounds, but without the depth of analysis necessary to fully support the point being made and negate the point of the Draft RIA. Thus, while a degree of doubt has been thrown on the estimates of the Draft RIA, insufficient data are available to go through the NPRM analysis point by point and reestimate the effect of each technology.

However, some confidential data were made available indicating the combined effect of a number of these techniques (e.g., increased injection pressure and enhanced aftercooling), as well as the projections of the levels feasible in this timeframe. While such data cannot be used to directly determine the fullest potential of one or more technologies, they do represent the most quantitative set of estimates available. Some degree of evaluation can be applied using the estimates of the Draft RIA. To facilitate their use here, these data have been combined into a single figure (Figure 2-2) which shows both current levels of NOx and particulate emissions and the manufacturers anticipated achievable levels. Superimposed on the best achievable emission control projections are the range of low-mileage targets as previously developed for the 6.0/0.60 standards (points A_1 and A_2) and the midpoint of the low-mileage targets for the engine-out standards of 4.0/0.40 (point E). A low-mileage target level of 4.2-4.6 g/BHP-hr for a NOx standard of 5.0 g/BHP-hr (vertical lines B) was also developed by the same procedure and the midpoint shown for comparison purposes. Particulate levels C

Figure 2-2

Heavy-Duty Engine NOx and Particulate Engine-Out Characteristics



and D correspond to the intercepts of lines C with the upper and lower bounds of the projected range of emissions using best available technology combinations as estimated by the manufacturers.

The first observation to make about the best technology estimates is that the upper limit barely passes through the design targets for the 6.0/0.60 standards. Thus, it represents fairly near-term "best technology." Second, the lower limit does not even approach the targets for the 4.0/0.40 standards. Given this, it is reasonable to evaluate the lower limit of the best technology curve against the projections made in the Draft RIA.

First, with respect to NOx, the Draft RIA analysis of 4.0 g/BHP-hr NOx relied upon large NOx reductions at constant BSFC for separate circuit and air-to-air aftercooling. This estimate was based on data from one GM/DDA engine and involved estimating NOx reductions beyond that evidenced by the data based on an estimated BSFC/NOx tradeoff for timing retard. Thus, no actual NOx data below 5.0 g/BHP-hr were available. Complicating matters was the absence of any particulate data in the study. While it can be assumed that these were not above 0.80 g/BHP-hr since BSFC was improving, particulate may have been well above 0.60 g/BHP-hr. Thus, these data may not be inconsistent with the curve in Figure 2-2, the problem may be a lack of particulate control, not NOx control.

Based on testing performed on the same DDA engine, the Draft RIA estimated that electronic engine controls (EEC) also had the potential for large NOx reductions at constant BSFC. Again, however, the estimate involved assuming a BSFC/NOx tradeoff curve for the engine and using timing retard against a BSFC improvement to estimate NOx emissions at constant BSFC. A 6.0 g/BHP-hr NOx level was the lowest actual data point in this analysis.

Many manufacturers stated that this analysis overstates the benefit of EEC. Some argued that the NOx benefit of EEC depends on the final NOx level (i.e., its benefit is large at 6.0 g/BHP-hr NOx and negligible at 4.0 g/BHP-hr). Others argued that the benefits of enhanced aftercooling and EEC were mutually exclusive, due to the fact that combustion efficiency limits the use of either technology and determining when both BSFC and particulate emissions begin to increase dramatically. Without data or sophisticated combustion analysis, it is impossible to prove or disprove these comments. However, these data could be consistent with that in Figure 2-2, given that particulate emissions are unknown.

With respect to particulate control, the Draft RIA analysis was much more general and based on less data than that for NOx, as 0.40 g/BHP-hr was not the primary proposed standard. The most feasible technique for the 1990 timeframe was high-pressure fuel injection. The only data available were steady-state emissions on one engine. The other technologies were 1) injection rate modification and/or modulation which would require significant advances in injector technology, 2) ceramics, which are not progressing as fast as some had projected a year ago, and 3) conversion to methanol fuel, which though technically feasible requires the establishment of a fuel distribution system (except for buses, as discussed below). Otherwise, small improvements could be expected from general BSFC improvements, and for additional optimization of injectors and combustion chambers. Thus, little data exist with which to refute the data in Figure 2-2 and it must be taken as the best estimate of technology in the 1991 timeframe at this time.

Given this, a 5.0 g/BHP-hr NOx standard for 1991 appears most reasonable instead of the proposed 4.0 g/BHP-hr standard. This is principally because of the adverse tradeoff between NOx and particulate which appears likely. While a 4.5 g/BHP-hr NOx level may be potentially achievable, particulate emissions appear to begin increasing at a distinctly higher rate below 5.0 g/BHP-hr NOx. Also, below 5 g/BHP-hr NOx, particulate emissions could in some cases increase well above 0.6 g/BHP-hr, making trap application very difficult. This would be particularly true with respect to the 1991 0.1 g/BHP-hr particulate standard for buses. The BSFC tradeoff would also begin increasing dramatically here, as well.

With respect to particulate, the range of expected low mileage engine-out particulate levels corresponding to the target level required for a NOx standard of 5.0 g/BHP-hr would be 0.42-0.54 g/BHP-hr (levels C and D in Figure 2-2). If it is assumed that trap-based standards are implemented in 1991 and 1994 (i.e., pressure to control particulate continues through the 1994 timeframe), then it is likely that progress will continue to be made in reducing engine-out particulate levels down to the lower best technology curve, resulting in an engine-out particulate level of 0.43 g/BHP-hr by 1994. If stringent 1991 non-trap particulate standard were implemented in 1991, it should also be able to reduce engine-out levels to 0.42 g/BHP-hr, but three years earlier. Thus, at best, a 1991 non-trap standard 0.50 g/BHP-hr appears achievable.

These levels are at least partially proposed by two manufacturers. Cummins recommended (at the public hearing on the NPRM) 1992 target standards of 4.5 g/BHP-hr NOx and 0.50

g/BHP-hr particulate. Daimler-Benz recommended 1990 standards of 5.1 g/BHP-hr NOx and 0.60 g/BHP-hr particulate. Other commenters either did not recommend any alternative standards to 4.0/0.40 g/BHP-hr or recommended retaining the 6.0/0.60 g/BHP-hr standards indefinitely.

b. Effect on Fuel Economy

As all commenters stated that the 4.0 g/BHP-hr NOx standard was infeasible, no estimates of its effect on fuel economy were made. Nor were any comments received addressing the effect of a 5.0 g/BHP-hr NOx standard. However, the latter can be estimated from the 1985 California/Federal comparison conducted above.

As in that section, there are a number of differences between the 1985 California 5.1 g/BHP-hr standard and the 1991 Federal standard of 5.0 g/BHP-hr. First, the Federal low-mileage target is slightly more than 0.1 g/BHP-hr lower than that in California. This would tend to slightly increase the fuel economy penalty. Second, six years of leadtime exist between the California and Federal situations to develop improved technology. Third, any adverse BSFC effects would affect Federal sales, which is roughly 10 times larger than California's. Both the available leadtime and the potential national sales impact, manufacturers would be expected to do all that is possible to eliminate any BSFC effect, as opposed to the California approach, which is more short-term, quick-fix oriented.

Given that significant NOx control technologies such as electronics, separate-circuit aftercooling, and air-to-air aftercooling are not currently present at all in California, and given their projected widespread use by 1991, it would appear that the additional leadtime and potential national impact would overwhelm the first. Overall, it would not appear unreasonable to project the same long-term fuel economy impact here as that projected in the NPRM for the 4.0 g/BHP-hr standard, zero percent. However, due to uncertainty in this analysis, and the projection that the BSFC/NOx curve begins to turn sharply upward at approximately a 5.0 g/BHP-hr standard, a long-term 0.5 percent fuel economy penalty may occur. In the short-term, a slightly higher 1.0 percent penalty may be experienced.

3. Particulate Traps

In response to the NPRM, the Agency received a large number of comments directed towards its heavy-duty trap feasibility analysis. As explained above in the synopsis of the NPRM analysis, the Agency concluded that traps were feasible for 1990 model year HDDEs, extrapolated from the status of light-duty trap technology and the design effort necessary to adapt this technology to heavy-duty usage. The comments were both supportive and critical of EPA's analyses and conclusions. This part of the regulatory impact analysis will respond to the comments, concentrating on the points of the analysis with which the commenters disagreed. New information that is pertinent to the heavy-duty trap feasibility question will also be incorporated. The comments will be addressed in the same format used in the previous analysis: light-duty trap status; LD/HD differences; heavy-duty trap status; and emission levels. In addition, the leadtime issue will also be addressed.

a. Light-Duty Trap Status

The status of light-duty trap oxidizers was generally not addressed by the commenters. The notable exception was General Motors. GM's position is that technology is still not available to meet the promulgated 1987 light-duty vehicle and light-duty truck standards. The extensive LDT testing (200 alternative fuels and fuel additives combined with over 150 trap materials in over 500 traps) conducted by GM has not resulted in an identification of a LD trap that can be committed to a production program. Thus, GM strongly objected to EPA's conclusion that light-duty traps are technically feasible for 1987 model year vehicles.

General Motors' comments notwithstanding, the Agency's position in the NPRM was borne out by Mercedes-Benz's certification of its 3L turbodiesel, equipped with a trap to meet the California Air Resources Board (CARB) 1985 model year standards.[8] CARB's 1985 standard for California light-duty diesel vehicles is 0.40 grams per mile (g/mi) particulates, to be further reduced to 0.20 g/mi in 1986 and 0.08 g/mi in 1989. In addition to its 1985 California LDDVs (which are also sold in other western states), Mercedes-Benz plans to add traps to all its U.S. sold 3L LDDVS in 1986, a year prior to the promulgated 1987 0.20 g/mi standard.

Mercedes-Benz is not alone in certifying a trap-equipped LDDV. Volkswagenwerk AG (VW) plans to install a trap on its larger diesel LDV (Quantums) in California beginning in the 1986 model year.[7] VW intends to equip all federally certified Quantums with trap-oxidizers the following year to comply with the 1987 LDV particulate standards. The trap applications of Mercedes and VW are proof that trap-oxidizers are a viable form of light-duty particulate emissions control.

b. Light-Duty/Heavy-Duty Differences

The manufacturers which commented agreed with EPA's analysis of the differences between light- and heavy-duty applications that must be considered in the design of a heavy-duty trap oxidizer. Comments from the manufacturers restated these differences (engine size and load factor, operating conditions and temperatures, durability, and ash accumulation), adding very little to what was previously reported in the draft analysis. The design efforts continue to be directed towards a suitable regeneration system that can handle the increased exhaust flow of the heavy-duty engine environment and the generally lower exhaust temperatures of a turbocharged engine. The commenters believe that the greatest design challenge is the required durability of a heavy-duty trap as opposed to a light-duty trap.

While no one found fault with the Agency's identification of these design obstacles in the adaption of trap technology to heavy-duty use, some of the manufacturers strongly disagreed with the Agency's conclusions that these obstacles are not insurmountable and traps would be technically feasible by the proposed model year (1990). However, none presented specific data or engineering analysis to demonstrate a LD/HD difference to be an insurmountable obstacle. The views of the NPRM were further reinforced by a document prepared for the Agency by Energy and Resource Consultants (ERC), an independent contractor.[6] This report concluded that light-duty trap technology can be adapted to heavy-duty use with additional development time beyond the effective light-duty trap standard date; line-haul trucks require an extra 3-4 years, as their operating conditions are the most dissimilar to light-duty conditions, and the light heavy-duty vehicles whose operating conditions are more closely related, require only 1-2 additional years at the most. Thus, the extrapolation contained in the NPRM should be retained. Manufacturers' heavy-duty test data are examined in the following heavy-duty trap status section.

c. Heavy-Duty Trap Status

The heavy-duty engine manufacturers' trap development results examined in the NPRM were obtained from comments the manufacturers submitted to EPA in 1982 following the initial 1981 particulate NPRM (46 FR 1910) and also from ensuing meetings between representatives of HDD manufacturers and EPA staff. The latest comments received in response to the recent NOx/particulate NPRM added very little test data to what was evaluated in the NPRM. The following paragraphs will review and examine the current status of heavy-duty trap development work as reported by the manufacturers.

GM submitted a summary of trap development and testing performed from 1981 through 1983 on HDDEs, much of which had previously been submitted to the Agency for review. The successful accumulation of an additional 70,000 kilometers on a dump truck equipped with a one-piece monolith trap on a 4-stroke turbocharged 8.2L diesel engine was the only new HDDE testing information received from GM. While GM's statement that the accumulated mileage (80,500 Km total) is short of the expected service life of this type of vehicle and the driving cycle followed was not representative of actual conditions is correct, trap feasibility in some future year does not require that traps be fully developed today. In this light, the Agency views this latest test result as extremely promising. At this stage in the design of traps, failures are expected; there is sufficient time to work out trap durability and regeneration control problems. Despite this, GM feels that traps are infeasible for production release for the 1990 or 1991 model year; GM refuses to commit itself to the feasibility of traps in the forseeable future.

Other manufacturers commented on the feasibility of traps based on experience in their heavy-duty trap programs. Due to their laboratory and field testing results, during the last two years, International Harvester is quite pessimistic about the feasibility of traps, with durability being the main design problem. Field experience, to date, has involved durability testing with three types of traps on a 6.9L light heavy-duty engine. Yet despite failures due to inadequate regeneration, IHC is willing to work towards a trap standard in the 1991/1992 time frame. Mack also is not confident that the durability of trap systems will be assured. Although Mack expects regeneration and its control to be feasible, trap durability remains too much of an unanswered question for Mack to state a definitive view on trap feasibility. Current work is aimed at accomplishing regeneration in actual vehicle use; initial results produced over 6,000 miles of successful operation. Caterpillar believes that trap technology may not be available for production by the proposed 1990 model year; however, Caterpillar did not mention a feasible implementation date beyond 1990.

As indicated in its comments, Cummins is at an early stage of heavy-duty trap development. If EPA commits itself to reassessing the technical feasibility of a trap standard by December 31, 1987, Cummins would feel comfortable with a 1992 particulate standard of 0.25 g/BHP-hr. However, Cummins added the caveat that it does not envision traps by 1992. Even though Volvo White considers current HD trap technology to be virtually non-existent, it believes that trap technology will be available and qualified by 1991 (as will be discussed below, this is conditional on the control of sulfur in diesel fuel).

Daimler-Benz, with the furthest developed heavy-duty trap program, was the sole HDE manufacturer to agree with the NPRM's proposed 0.25 g/BHP-hr trap-based particulate standard date of 1990 model year implementation. (This also is conditional on fuel sulfur control, in addition to an allowable maintenance condition discussed below.) As described in its 1982 comments to the Agency, Daimler-Benz is concentrating on the development of a trap made of wound ceramic fiber. The latest comments indicate that considerable development progress has been made in the last two years. Still, much development remains, including the optimization of trap design and increasing the trap durability through an optimized regeneration system. Current results of urban bus applications of the traps show a minimum trap service life of 100,000 miles, and a maximum service life of less than 150,000 miles. With these encouraging test results at this stage in the design of traps, the Agency sees no reason that the allowable maintenance interval of 150,000 miles is not feasible for traps, as Daimler-Benz indicated in its comments. As EPA has stated previously in relation to trap feasibility, there is sufficient time to work out trap durability problems.

The Manufacturers of Emission Controls Association (MECA), whose member companies are supplying the trap materials being tested by the HDDE manufacturers, strongly supported the feasibility of trap-based standards. Although recognizing that development work remains, MECA stated that a trap-based standard is achievable, citing worldwide test and development work by its member companies.

Overall, progress in heavy-duty trap development has not matched that in the light-duty area over the past two years. Much of this difference, however, can be attributed to the lack of a firm target, which can only be a promulgated standard. While significant steps still need to be accomplished in the heavy-duty area, the finding that light-duty trap technology can be extrapolated to heavy-duty engines and thus, traps are feasible for future heavy-duty usage, remains essentially unchallenged. The key issue is actually leadtime, which will be addressed further below.

One issue not considered in the NPRM, and which should be addressed here was that raised by Daimler-Benz, Volvo White, and several other manufacturers concerning diesel fuel sulfur content and its relationship to the heavy-duty engine environment. Daimler-Benz was very concerned about trap-plugging by non-regeneratable particulate matter; using a European diesel fuel, Daimler-Benz found an average of 35 percent of the non-carbon deposits left after regeneration to be sulfates. While none of the other commenters discussed the issue of trap-plugging by sulfates, Caterpillar and IHC expressed concern that high sulfate emissions resulting from high sulfur fuel will make up a significant portion of EPA's proposed 0.25 g/BHP-hr standard and possibly exceed it. A reduction in the sulfur content of diesel fuel was recommended by Daimler-Benz, IHC, Mack, and Volvo White; failing this, or as an interim step, the manufacturers recommended that EPA should adopt a correction factor as part of its particulate test to account for the sulfur portion of the particulate emissions.

The data available are not sufficient to allow a full analysis of this issue at this time. Not enough is known about the Daimler-Benz trap to understand why sulfate plugging is a problem there and not elsewhere and what, if any, solutions are possible short of reducing the sulfur content of diesel fuel. The comments of other manufacturers presumably apply to catalyst substrate traps, which generally showed the same problem on light-duty diesels. (Mercedes' trap is the exception to this.) As this is not the only trap design, or even that believed to be the most feasible (which is generally thought to be burner or fuel additive regenerated), its elimination from consideration may not affect overall feasibility. Also, while limited areas in California require low sulfur diesel fuel, the cost of such control on a nationwide basis has not been determined and would require significant study.

Given the uncertainty in the relationship between this issue and feasibility, it should not preclude implementation of any trap-based standard. However, the Agency is open to further discussion in this area and will, on its own, be analyzing the cost of controlling the sulfur content of diesel fuel in the future.

Many of the comments on the sulfur issue addressed the measurement of water, absorbed on the sulfate, as particulate emissions. Their concerns center on the fact that it is very difficult to reduce the current conversion of gaseous sulfur dioxide to sulfate (which is only 2-4 percent). As the particulate standard becomes more stringent, this sulfate,with its water,comprises more and more of the allowable emissions. EPA is currently examining a number of different approaches which can be incorporated into the test procedure to minimize the measurement of water. Although commenters recommend a correction factor added to test procedure to counter the problem, the time constraints on this rulemaking did not allow sufficient time to determine the optimum approach. Thus, no such revisions in the test procedures will be made here; potential changes will be addressed in a later workshop and further study of this issue. With respect to the sulfate itself, it should be measured as part of the particulate emitted as it is definitely inhalable and affects human health. As the typical conversion of sulfur dioxide to sulfate has been occurring in all previous heavy-duty particulate measurements, and thus, estimates of trap efficiency, feasibility is not affected. Feasibility is only an issue when sulfate is significantly increased by a catalyst, which was discussed above.

Some concern was also expressed regarding the fuel economy effects of trap-oxidizer use. A trap fuel economy penalty incorporates the fuel economy losses that result from an increase in backpressure and also the increased fuel consumption attributed to the energy requirements of positive regeneration. The NPRM analysis cited a two percent fuel consumption penalty as the worst penalty which would be observed with HD traps.

Ford argued that the implementation of traps to HDDEs will cause fuel consumption to increase by about three percent, approximately two percent of which is due to the backpressure portion of the penalty (the average of the "clean trap" penalty of about one percent and the "loaded trap" penalty of about three percent). A second manufacturer, Cummins, calculated an approximate fuel economy penalty of 2.6 percent for a 60-liter trap; this value was not based on actual testing. As reported in the NPRM analysis, 1.6 percent of the Cummins estimated penalty is due to the increased backpressure and 1.0 percent due to burner-initiated regeneration occurring at 100-mile intervals. The remaining HDDE manufacturers did not comment on the fuel economy effects of traps. The Department of Energy (DOE) noted a zero to one percent fuel economy penalty as a total contribution from the backpressure on the regeneration.

The effect of trap use on the HDDE fuel economy is of course dependent on the trap system design, including trap type, trap size, regeneration type and frequency of regeneration. Thus, it is reasonable to expect a range of fuel economy penalities for the industry, assuming a variety of trap system designs will be used. The one to two percent fuel economy penalty range documented in the NPRM analysis is bracketed by the fuel economy losses submitted by Ford, Cummins and DOE, with the manufacturers' values on the high side and DOE's range on the low side.. EPA's own test data tend to support the NPRM range.

In 1983, EPA tested a Corning ceramic trap on both a bus engine and a bus chassis.[9] The trap caused up to a 2 percent fuel economy penalty on the bus chassis, but caused no penalty at all on the engine. Steady-state testing of the engine at high loads, where the effect should be largest, also showed no effect.

Also in 1984, EPA tested a 400 hp HDDE with a number of trap designs. Over the EPA transient test, a Johnson-Matthey trap mounted close to the exhaust of the turbocharger showed no fuel penalty. A Corning ceramic trap mounted between the exhaust manifold and the turbocharger showed a penalty of 2.4 percent. The Corning ceramic traps similarly mounted in parallel showed a 9 percent fuel economy penalty.

The before turbocharger location maximizes the exhaust temperature at the trap, but also maximizes the fuel penalty as it directly affects turbocharger effectiveness. This is evidenced by the fact that two traps in parallel cause a greater fuel penalty than a single trap. Normally, use of two traps would reduce backpressure and reduce any fuel economy penalty effect. However, here the traps are also acting as heat sinks, and are removing useful energy that otherwise may be used by the turbocharger. Two heat sinks are worse than one. It is extremely unlikely that such a design would be used on a HHDE where fuel efficiency is of upmost importance. Thus, the 2.4 percent penalty, generated by this research program aimed primarily at identifying conditions of spontaneous regeneration, can be taken as a definite upper limit of any fuel penalty.

Also of importance is trap size; an increase in trap size would reduce backpressure and reduce the fuel economy penalty. In costing trap systems in Chapter 3, larger trap sizes were used than those used in the NPRM analysis or those used in the EPA tests above. This was done recognizing that even a 0.5 percent decrease in fuel economy penalty would overwhelm the added cost of the larger trap.

Even so, the trap size projected in Chapter 3 for HHDEs is not as large as the 60-liter trap used by Cummins on its 270 hp engine, which showed the 1.6 percent backpressure related penalty. This sizeable penalty from such a large trap is somewhat of an anomaly. For example, data supplied by GM for a much smaller trap, even accounting for the fact that the engine was smaller, showed backpressure levels one-third to one-half lower than those resulting from the Cummins trap. This discrepancy may be due to trap location or operating conditions. The GM backpressure levels result from actual vehicle road tests, while Cummins' value was not from actual condition testing. Thus, the Cummins trap seems to have caused an unusually high fuel economy effect and a .5-1.0 percent backpressure fuel penalty range based on GM's data is not unreasonable.

With respect to regeneration, it is possible to directly estimate the fuel penalty associated with use of a burner based system. The burner used in the EPA bus testing and that forming the basis for the burner cost estimate made by Jack Faucett Associates were rated at 100,000 btu per hour.

Using an estimated burn time of 5 minutes per regeneration, regeneration frequencies of 100 miles (used in Cummins test) and 175 miles (maximum of 145-175 mile range used in GM test), and HDDV fuel economies taken from the MOBILE3 conversion factor analysis,[10] the burner related fuel penalty ranges between 0.2 and 0.5 percent. This is much lower than the one percent penalty estimated by Cummins.

Thus, overall a 1-1.5 percent fuel penalty would appear reasonable for a burner based ceramic trap system or approximately 0.5 percent attributed to the burner and approximately 1 percent attributed to trap backpressure. However, a fuel additive based trap system would not have the fuel penalty associated with the burner. This type of system now appears to be among the most promising. Thus, a range of 0.5-1 percent fuel penalty will be used.

Commenters also addressed the potential safety problems associated with trap usage. The American Trucking Association stated that the high temperatures required for uncatalyzed oxidation of accumulated particles and the possible dangerous emissions from catalyzed traps are obstacles in the design of safe trap oxidizers. Although Cummins did not detail its trap safety concerns, Cummins did state that significant work is needed in the safety area prior to the implementation of traps.

EPA does not dispute that the use of trap oxidizers poses potential safety problems. But the Agency believes that through careful design of the trap system the associated risk can be reduced to manageable levels. One example of a safety design is to monitor the trap temperature to control regeneration. For a burner system, flame sensors can shut down the fuel flow if necessary. The trap design costed in Chapter 3 includes a number of such sensors. As for the danger of toxic emissions from catalyzed traps, we assume ATA is referring to sulfate emissions, which are a recognized problem with catalyzed traps. EPA is not aware of any hazardous emissions from non-catalyzed traps, except possibly for catalyzing fuel additives, which would only be introduced by the engine manufacturer if safe. It is true that work is needed in the safety area as traps are developed. However, the two production or production-ready LDD trap systems appear to be quite safe and no HD/LD differences appear to prevent such safe design of HDD traps.

d. Emission Levels

This section deals with comments on the trap-based standard of 0.25 g/BHP-hr, separating the issue of trap feasibility, as examined above, from engine-out and trap deterioration and trap efficiency, as examined here. The emission levels specific for the more stringent 1991 model year bus and 1994 model year HDE 0.10 g/BHP-hr standard are also examined.

EPA's determination of the design target level generated a great deal of comment from the manufacturers. Commenters were critical of the values used in the analysis for the deterioration factor of engine-out particulate emissions and also the deterioration factor of the trap-oxidizer. The comments on the deterioration factor of the engine-out particulate emissions and also the AQL adjustment factor were addressed in a previous section and will not be repeated here.

Several commenters disagreed with the Agency's position that there is no significant deterioration of particulate emissions with the use of a trap. They claimed that traps do deteriorate and thus, a multiplicative DF of 1.0 is unrealistic. Reasons for trap deterioration, according to Ford, include: micro-cracks resulting from thermal stress and high temperatures, leakage at the trap end seals due to warpage, an increase in the soluble organic fraction and regeneration control system deterioration. In the NPRM analysis, EPA did not explicitly consider the occurrence of micro-cracks, leaks, or an increase in the soluble organic fraction. All are theoretically possible, but there are no data to support their likelihood; the present durability data show no deterioration. Therefore, a trap deterioration of zero is not unrealistic at this time. However, even if trap deterioration were a factor of 1.2, it would affect feasibility; it would only require traps to be applied to an additional 3-10 percent of the fleet, depending on the standard level and model year being considered.

The subject of trap efficiency, the most variable factor effecting the emission level, was also addressed in the comments. One commenter (Ford) did not believe that light-duty truck trap efficiencies necessarily apply to HDE trap efficiencies, although it presented no analysis to support this opinion. Another commenter (Cummins) brought up the possibility that trap efficiency depends on the driving cycle and also the type of particulate matter; data indicated that trapping efficiencies for the soluble fractions are about 20 percent less than for the dry particulates in a ceramic monolith trap.

The NPRM analysis cited an efficiency range from 70-90 percent for the ceramic wall-flow monolith trap and a range from 50-80 percent for the wire mesh trap's collection efficiency. Daimler-Benz's test results show the collection efficiency for its ceramic fiber wound trap increasing with the filter loading regardless of the initial trapping efficiency. (An unloaded trap with a 60 collection efficiency, increased to 80 percent efficiency with 15 percent loading, 90 percent efficiency with 40 percent loading, and 97 percent efficiency with 70 percent loading.) GM commented that it hasn't seen the efficiencies that EPA reported out of its traps. However, at another point in its submittal, GM stated that "in spite of repeated structural failures with ceramic monoliths, we have continued their development because of their high trapping efficiency and overall potential once the control problems for a consistent regeneration are resolved."[11]

Based upon the above, an 80 percent efficiency was chosen in the NPRM to represent an obtainable feasible trap efficiency level in the 1990 timeframe. One commenter disagreed with this efficiency level referring to testing of a trap-equipped bus engine conducted by Southwest Research Institute (SwRI) for EPA.[9] The transient test particulate emissions of the DDAD 6V-71 engine were reduced 61 percent using a ceramic trap over the FTP; over a bus cycle, total particulate was reduced 68 percent. This testing was done on an old engine notorious for a high soluble organic fraction of its particulate, which explains the low collection efficiencies. Current technology engines have much lower HC emissions and lower soluble organic fractions (SOF) which should result in a much higher trap efficiency as indicated in Cummins' comments that trap efficiency increases as the SOF decreases. Other testing conducted by SwRI[12] did result in a higher trap efficiency; a Cummins NTC-400 engine equipped with a Corning trap was effective at reducing particulate emissions by 85 percent. Thus, an 80 percent efficient trap is still reasonable with respect to a 0.25 g/BHP-hr standard, if not on the low side of what traps' actual collection efficiency will be.

Applying the trap deterioration factor, SEA adjustment factor and the trap efficiency to the engine-out target level, (0.42-0.54 g/BHP-hr from above), yields an emission level of 0.10-0.13 g/BHP-hr. Thus, at the 0.25 g/BHP-hr standard, traps will not be required on all engines; the technically most difficult applications will be able to be excluded from trap usage, which is desirable given the new nature of this technology. With averaging, approximately 70 percent of the HDDEs will be trap-equipped in order to meet the 0.25 g/BHP-hr. The percentage of the fleet requiring traps should decrease to approximately 60 percent by 1994, as the engine-out target level decreases to 0.42 (discussed in Section above); this assumes a trap efficiency of 85 percent.

Limiting traps to only highly efficient, ceramic wall-flow monoliths, even lower levels can be achieved. Thus, assuming 85-90 percent efficient traps, the engine-out target level of 0.42-0.54 g/BHP-hr results in a emission level of 0.05-0.08 g/BHP-hr,which would comply with the 0.10 g/BHP-hr standard.

By 1994, the engine-out target level is projected to be 0.42 g/BHP-hr. Assuming unchanged deterioration and SEA adjustment factors and 90 percent efficient traps, this results in an emission level of 0.05-0.06 g/BHP-hr. Under a 0.10 g/BHP-hr standard and with averaging (excluding urban buses), roughly 90 percent of the HDDEs will be trap equipped.

In commenting on stringent particulate emission standards, in addition to trap technology, many commenters addressed the use of methanol fuel in diesel engines as a method for further reductions of HDDE particulate emissions. Views on this subject were widely held. NRDC and other environmental groups believed that EPA should establish both NOx and particulate standards based upon the use of methanol as a fuel in new engines and also set regulations to assure the existence of a supply and distribution for methanol to fuel heavy-duty engines.

Comments from HDDE manufacturers expressed caution over the use of methanol fuels. Saab-Scania stated that it was not prepared to provide methanol-fueled engines in transit buses in 1990 due primarily to the uncertainty of the unregulated pollutants and their health effects. This comment was fairly typical of those by other manufacturers addressing this issue; concern over the technological aspects of methanol-fueled HDDEs was a minor issue compared to the potential health risks of methanol.

New Jersey Transit and other public transit authorities believed that EPA should analyze and further evaluate the feasibility of methanol as an alternative fuel, expressing concern about the difficulties related to storage, distribution, operating range limitations for vehicles and the risks of formaldehyde emissions.

While EPA continues to believe in the potential of methanol in this area, it considers it premature to actually set standards requiring the use of methanol. Many basic questions remain to be dealt with before widespread adoption of methanol fuel will be possible. Therefore, while continuing to encourage the development of methanol-based technology, EPA is taking no action at this time on methanol-based standards.

e. Leadtime

i. 0.25 g/BHP-hr Standard

In its NPRM analysis of leadtime, EPA concluded that there appeared to be sufficient time for the manufacturers to design, develop, and prepare trap oxidizers for 1990 model year HDDEs. In their comments, all the manufacturers, some to a greater degree than others, were cautious in predicting a date for traps to be in production on HDDEs. Only one commenter (Daimler-Benz) agreed with the Agency's proposed implementation date, albeit conditionally, as discussed above. The other manufacturers disputed EPA's analysis that traps would be feasible for 1990 model year application. In their submittals, the majority of the manufacturers did provide alternative dates to the proposed 1990 model year effective date. As reviewed, International Harvester and Cummins indicated a willingness to work towards a trap-based standard in the 1991 to 1992 timeframe. Volvo White expressed its belief that traps will be available and qualified by 1991. Ford did not believe traps could be implemented prior to the 1991 model year, if then. The remaining manufacturers of HDDEs were not certain at what date in the future traps would be available.

In re-examining the necessary leadtime for the implementation of a trap-based standard, it appears the effective date should be delayed from the proposed 1990 model year to the 1991 model year for several reasons. First, there has been little apparent progress in HD trap technology development by the heavy-duty industry over the past two years (Daimler-Benz being the most notable exception). Light-duty trap technology has continued to progress and insofar as heavy-duty trap technology is an outgrowth of light-duty technology, heavy-duty technology has progressed even without any overt effort by HD manufacturers. However, not all of this lack of progress over the past two years is recoverable and an extra year of leadtime would appear reasonable.

Second, the promulgation of these standards, is somewhat later than originally anticipated. (March of 1985 vs. late 1984). While not constituting an entire year, the leadtime was tight to begin with and an extra year is reasonable for this reason as well.

Third, the Clean Air Act requires that revised heavy-duty HC, CO and NOx be at least three years apart. While not applying directly to this particulate standard, it appears reasonable to follow this approach in this case. The 5 g/BHP-hr NOx standard is being implemented in 1991 and it is reasonable to have the particulate standard change at the same time.

ii. 0.10 g/BHP-hr Standard

In order to comply with the more stringent 0.10 g/BHP-hr standard, traps must be 85-90 percent efficient depending on their engine-out particulate levels. Presently this efficiency cannot be obtained by all trap designs, and the design of high-efficiency traps is generally considered to be technically more difficult than lower efficiency designs.

In their comments on a 0.10 g/BHP-hr standard, most of the HDDE manufacturers argued strongly that this standard was not achievable. Only Daimler-Benz and Volvo White believed that the necessary trap efficiencies were feasible and this was in relation to the proposed bus standard, as discussed below. The Engine Manufacturers Association (EMA) and Ford believed that trap efficiency must be 85 percent to meet a 0.10 g/BHP hr standard and believed this level not possible. GM added that EPA disregarded the variability of trap efficiencies in assuming a 90 percent efficient trap was possible. Aside from the general comments on trap efficiency, technical comments did not address specific difficulties involved in meeting a 0.10 g/BHP-hr as compared to a 0.25 g/BHP-hr standard (i.e., obstacles in the way of obtaining a higher trap efficiency).

The majority of the commenters felt this level of particulate emissions was unobtainable for two reasons. The first being that the required trapping efficiency would not be possible by the 1991 model year. The other reason was discussed previously: high sulfate emissions, resulting from high sulfur fuel, will exceed a 0.10 g/BHP-hr standard. While Daimler-Benz shared the concern over the sulfur issue, the HDDE manufacturer stated that the 0.10 g/BHP-hr standard was obtainable for 1990 model year buses, depending on an improvement to the particulate measurement accuracy at low levels. The Manufacturers of Emission Controls Association also believed that a 0.10 g/BHP-hr standard was achievable for 1990 model year buses.

Trap efficiency may be increased by either employing a different trap type or by making design changes to a lower efficiency trap. Of the trap designs currently considered promising, the ceramic monolith trap is the most efficient - its efficiency can be above 90 percent. A ceramic trap efficiency is related to the porosity of its honeycomb matrix; high porosity results in low efficiency and vice versa. Engineering challenges that result from a decrease in the trap porosity (increase in trap efficiency) include faster backpressure rises, which must be compensated by increasing the trap size or by more frequent regeneration. The former solution may also solve the potential increase in ash or fuel additive accumulation. The latter may not. A larger trap can create additional design problems itself (greater stresses and heating requirements for regeneration) as were discussed in the NPRM analysis of light-duty/heavy-duty design differences. More frequent regeneration is fairly simple for a burner-based system, but may be much more difficult for catalyzed or fuel-additive based systems where naturally occurring temperatures are relied upon to induce regeneration.

Due to the increased difficulty in designing a higher-efficiency trap capable of complying with a 0.10 g/BHP-hr standard, the technical feasibility of all 1991 model year HDDEs complying with this standard is not likely. By establishing a 1994 0.10 g/BHP-hr standard, the Agency believes that the additional three years will allow for the development of higher efficiency traps with more time to optimize performance and durability while minimizing cost.

The overall difficulty of achieving these high efficiencies also depends on the number of engines needing to be so equipped. It is likely that a number of trap systems employed to meet the 0.25 g/BHP-hr averaging standard will be 85-90 percent efficient. Others will be less efficient. Thus, for a few engine urban transit buses, for example, a 0.10 g/BHP-hr standard should be quite feasible. In actuality, few bus engines are currently marketed in the U.S. GM dominates the market with its 6V-92TA and 8V-92TA bus engines. Cummins has sold a small number of its VTB-903 engines in buses in the past, but is not currently doing so. A small number of foreign-based manufacturers, such as M.A.N. and Daimler-Benz, have recently begun to market bus engines in the U.S. Thus, bus engines represent a relatively small subset of HDDEs. Developing a trap-oxidizer system for transit bus use may also be considerably easier than for most HDE applications. An EPA-sponsored report by Energy Resource Consultants, Inc.[6] mentions the following reasons this may be so:

1. Durability and reliability requirements would not be nearly as strict as for most other types of heavy-duty vehicles.

2. Buses have a rather predictable operating cycle, and and one which includes a great deal of acceleration. The frequent occurrence of moderate high exhaust temperatures as a result would help to make a self-regenerating system feasible.

3. Transit buses universally receive regular service, often on a daily basis.

Thus, at minimum, bus engines should be no more difficult to trap-equip than other HDDEs and, at best, could be much easier to trap-equip. Coupled with their small number, developing high-efficiency traps for bus engines should be feasible at the same time as traps are generally employed on HDDEs, or 1991.

Equipping all HDDEs with high-efficiency traps will require additional time beyond 1991. Having buses operating with such traps will certainly provide useful data, but such data cannot be employed any sooner than three years after the buses begin service, since time is required to obtain the data and design and tooling must also be performed. Of more use will be durability data generated on prototype non-bus HDDVs equipped with high-efficiency traps after the bus engine designs have been set, but prior to bus introduction. Providing only two years between standards can reasonably be ruled out due to the need to apply such traps to line-haul HDDEs, which have very long lives and which require extensive durability data. The argument can be made that three years should be sufficient to incorporate such durability data. As this also coincides with the Act's requirement for HC, CO, and NOx standards, it appears the most reasonable interval time as well.

C. Conclusions

1. Near- and Mid-term NOx and Particulate Standards

As a result of the proceeding analysis of the comments, EPA has concluded that the proposed standards of 6.0 g/BHP-hr NOx and 0.60 g/BHP-hr particulate are technologically feasible and that the appropriate date for implementation of these standards is the 1988 model year.

EPA has also concluded that engine-out emission standards of 4.0 g/BHP-hr NOx and 0.40 g/BHP-hr for HDDEs are not technologically feasible using any known emission control technology. Information provided in the comments has, however, lead EPA to modify the NPRM analysis and conclude that an engine-out NOx emission standard of 5.0 g/BHP-hr is technologically feasible by the 1991 model year. The lowest feasible engine-out particulate level, given the 5.0 g/BHP-hr NOx standard, appears to be 0.50 g/BHP-hr.

With respect to fuel economy, the 6.0/0.60 standards are expected to cause a 0-2 percent fuel economy penalty in the near term and that this penalty will be erased by 1991. The NOx standard of 5.0 g/BHP-hr is expected to cause approximately a 1 percent penalty initially, decreasing to approximated 1/2 percent in a few years.

2. Trap-Based Particulate Standards

As a result of the proceeding analysis of the comments and additional information, the Agency concluded that trap technology is feasible for heavy-duty diesel engine application. This conclusion was extrapolated from the status of light-duty trap technology and the design effort necessary to adapt this technology to heavy-duty usage. Light-duty traps have been proven to be a feasible control of particulate emissions from light-duty vehicles. Although conditions specific to the HDDE environment require considerable development in order to apply LD trap technology to HD usage, these obstacles are not insurmountable and with adequate engineering effort traps should be a feasible control method of particulate emissions from heavy-duty vehicles.

EPA has also concluded that the 0.25 g/BHP-hr trap-based particulate standard should be feasible for 1991 model year HDDEs; the 0.10 g/BHP-hr trap-based particulate standard should be feasible for 1991 model year urban buses and for all 1994 model year HDDEs. The analysis determined that the 1991 model year HDDE standard, with averaging, will require 80 percent efficient traps on roughly 70 percent of the fleet. This would decrease to about 60 percent after the initial years. The 1991 model year bus standard will require the use of nearly 90 percent efficient traps on all buses. The 1994 model year HDDE standard will require the use of 90 percent efficient traps on roughly 90 percent of all HDDEs.

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CHAPTER 3

ECONOMIC IMPACT

This chapter analyzes the costs of complying with the new NOx and diesel particulate standards in light of the comments received in response to the NPRM. These comments at times supported and at times disputed the EPA cost estimates; some of these comments prompted revisions of the costs given in the NPRM, and are outlined below.

The chapter begins with a synopsis of the methodology used in the Draft Regulatory Impact Analysis (RIA) to generate the cost estimates in the NPRM. Following the synopsis is the Summary and Analysis of Comments, which is divided into three cost sections: LDT, HDGE, and HDDE. Within each section is a summary of the applicable comments, discussion of how the comments compare to the information contained in the NPRM, and any reanalysis as necessary. Each section closes with a summary of the final cost and cost-related values used in the final economic impact analysis. This is followed by a discussion of socioeconomic impacts.

I. Synopsis of the NPRM Analysis

This chapter as originally presented in the Draft RIA examined the compliance costs of the proposed NOx and diesel particulate standards for LDTs and HDEs. It included the manufacturers' fixed costs of pre-production (research, development, and testing (RD&T), including certification testing), and their variable costs of production (emission control hardware component costs), as well as user costs of increased purchase price, fuel economy losses, and maintenance cost changes. The chapter was divided into two sections which discussed, respectively, the actual manufacturer and user costs, and the socioeconomic impacts of such costs. The first section is the more lengthy one, and received the main bulk of the comments. It is summarized below. The socioeconomic impact section, which included manufacturer, regional, and national effects on sales, cash flow, employment, balance of trade, and consumer prices received comments on two issues only, and therefore need not be reviewed in full.

Commenters on costs focused on alternative values to the costs derived by EPA rather than on the methodology used, and therefore the methodology is described here only briefly. Any interested parties may consult the Draft RIA for more complete information on the cost derivation methodology and actual cost values which were presented in the NPRM.

A. Cost to Manufacturers

In EPA's analysis, manufacturer costs for each of the vehicle/engine groups -- LDT, HDGE, and HDDE -- included the fixed costs of RD&T and the variable costs of hardware. Fixed costs were determined by estimating the number of recalibrations, design modifications, and the amount of new testing necessary to convert present systems to those which could meet the standard. Numbers of calibrations needed per engine family were combined with numbers of engine families needing the work, estimated hours of effort per calibration, hourly rates for labor, overhead and parts, and a 10 percent contingency factor to derive a dollar value for total recalibrations. Similar estimates were made of the time necessary for redesign and for completely new, general system designs, such as that required for particulate traps.

Testing costs to prove mechanical integrity were based on miles of testing necessary, average speed, and hourly rates for labor and overhead; such test costs were shared with other testing programs when applicable. Certification testing costs included the same type of mileage accumulation costs, as well as fixed costs of $1,500 per emission test for LDTs and $2000 per emission test for HDEs.

For LDT, HDGE, and 1987 HDDE proposed standards, it was assumed that these fixed costs would be incurred in the two years prior to implementation of the standards; for the 1990 HDDE standard, four years were allotted due to the longer development time needed for trap-oxidizer systems. The sum of all these costs was apportioned over five model years for LDTs, and three model years for HDEs (due to introduction of the second set of HDE standards after three years). Costs were presented in both undiscounted and discounted forms. Discounted costs were calculated at a 10 percent discount rate to the first year for which the standard was applicable (1987 or 1990). These costs were then spread over projected sales to determine an average cost per vehicle or engine due to RD&T.

Variable costs to manufacturers arose from the addition of new hardware and, in some cases, credit was taken for the removal of old hardware components. For LDTs these component costs were developed using the Rath and Strong methodology[1] as discussed in the Draft RIA and include overhead and manufacturer profit. For HDGE and HDDE NOx and non-trap particulate control on HDDEs, component costs were developed from costs for similar pieces of equipment on current engines, with inclusion of factors for different material costs due to different component sizes. Particulate trap costs were taken directly from the Diesel Particulate Study.[2] These component cost estimates were combined with projections of the technology changes which would be necessary to meet the new standards, market shares of various technology mixes and vehicle/engine types, and projected sales, to develop both per vehicle/engine and aggregate manufacturer costs for hardware. Hardware costs were combined with RD&T costs, with appropriate discounting at 10 percent, to determine total manufacturer costs.

B. Cost to Users

Costs to users were based on increases in first cost at the retail price equivalent (RPE) level and additional operating costs due to changes in fuel economy and maintenance. The first price increase per vehicle includes the average hardware cost for that vehicle's new technology application and the per vehicle share of RD&T, which is apportioned over the three or five years after implementation of the standard as discussed above.

The lifetime cost changes per one percent of fuel economy change were calculated from fuel price, average base fuel economy and lifetime mileage per vehicle or engine category, using a 10 percent discount rate. Overall fuel economy changes expected were estimated in the Technological Feasibility Chapter according to the types of technology necessary to meet the standard. Lifetime fuel economy costs due to the standard could thus be calculated by multiplying cost per one percent change by the amount of change expected.

Maintenance costs were determined from any additional maintenance operations deemed necessary for the new technology, the expected number of additional maintenance operations per lifetime, and the cost per occurrence. These costs were then discounted at the usual 10 percent rate, from point of maintenance to point of sale. The costs were then apportioned two different ways. In the first case, they were apportioned over just the engines requiring the new technology and the corresponding maintenance, and in the second case the costs were apportioned over all engines. In appropriate cases credits were taken for maintenance which would be reduced, using the same methodology. Maintenance costs, either negative or positive, were added to fuel economy costs and first price increases to give the total lifetime user cost of the standard.

Aggregate costs to the nation, including those to both manufacturer and user, were then calculated for each vehicle or engine group. Hardware costs plus operating costs of fuel and maintenance were multiplied by number of vehicles affected, according to future sales projections. As noted above, a 5-year period was used for LDTs and 3-year periods for HDEs. These values were discounted to the proposed year of implementation, and added to discounted RD&T costs, to yield the net present value aggregate cost in the year the standards begin. Costs to the nation were also expressed in terms of per vehicle investment in 1987. All values used throughout the chapter were 1984 dollars.

II. Summary and Analysis of Comments

A. LDT NOx Standard

1. 1988 NOx Standards

a. Cost to LDT Manufacturers

Comments on the manufacturer costs attributable to the new LDT NOx standards were neither numerous nor lengthy, with only two manufacturers estimating retail price increases due to hardware and RD&T. The price increases in the comments were stated without derivations, and the methods used by EPA to estimate the costs given in the NPRM were not challenged. The manufacturer and EPA final costs, however, were not based on comparable fleets. Manufacturer costs were based on only those vehicles requiring new technology, while the EPA final costs developed in the NPRM were expressed as an average over every LDGT or LDDT, including those vehicles which will already have the hardware in place prior to implementation of the standard. EPA developed an average per vehicle cost for a LDGT requiring new technology in the Draft RIA, as part of the process of developing the fleet average LDT costs. This cost ($140) was presented in the Draft RIA. The EPA and manufacturer cost estimates are as follows:

Retail Price Increase Per LDT

Draft Analysis	$35	LDDT Average
	$44-87	LDGT Average
	$140	LDGT with new technology
Chrysler	$80	LDT with new technology
Toyota	$100-250	LDT with new technology

As can be seen, when the same figures -- cost per vehicle with new technology -- are compared, those given by the manufacturers are comparable to those estimated by EPA in the NPRM. Therefore, EPA sees no need to alter its analysis of the LDT component cost values or RD&T costs which were used to develop the average per vehicle values presented in the NPRM.

i. Fixed Cost

In developing the costs for the final rule, the original allocation for RD&T costs estimated by EPA for this standard will be used here, but shifted one year to concur with the shift in the year of introduction of the standard. This amount is the sum of the RD&T costs for LDGTs and LDDTs, and totals $26,970,000.

ii. Variable Cost

The average costs have been updated to reflect manufacturer comments on projected technology mixes received in response to the NPRM. Present technology mixes are taken from 1985 model year certification data, which provides manufacturer sales projections by engine family and, hence, by emission control technology type. The manufacturer data from comments and the 1985 certification data provide the basis for revision of the projected technology mixes and subsequent revision of the average LDGT hardware costs, which are calculated in the same manner as used in the Draft RIA. The projected mixes were in most cases confidential on a manufacturer-specific basis, and are included here only in general form.

The new present (1985) and projected technology application mixes according to LDGT engine size are given in Table 3-1. The same information for all LDGTs combined is presented in Table 3-2. The 1985 model year mixes were converted to projected 1987 model year (pre-standard) mixes by applying technology changes on specific engine families as indicated by manufacturers in confidential comments to the NPRM. As noted in the NPRM, the comments verify that even with no increases in the stringency of the NOx standard, there is a clear trend away from oxidation catalyst systems to three-way-catalyst systems on LDTs, apparently for reasons such as improved driveability and fuel economy. The trend for LDGTs is predominantly toward three-way closed-loop systems as opposed to three-way open-loop systems. Therefore, this analysis projected that for the 1988 model year (the first year of the new standard), all remaining oxidation catalyst systems and all three-way open-loop systems will convert to three-way closed-loop technology.

The overall hardware cost for each vehicle undergoing a technology change, according to number of cylinders in the vehicle, is given in Table 3-3, which is a summary of Tables 3-4 through 3-6 in the Draft RIA. Costs are derived by subtracting the costs of hardware components removed from the costs of hardware components added; estimates of these costs were originally determined using the Rath and Strong methodology,[1] and are unchanged from the Draft RIA.

The hardware costs as presented in the Draft RIA and the projected change in the technology mix, as discussed above, are combined to give an average hardware cost upon implementation of the 1988 model year standard for LDGT$_1$s and for LDGT$_2$s as follows:

Table 3-1

Light-Duty Gasoline Trucks
Percent Technology Usage By Model Year and Engine Size

	Oxidation	Three-Way Open-Loop	Three-way Closed-loop	Three-Way Open-Loop plus Oxidation	Three-Way Closed-Loop plus Oxidation
$LDGT_1$:					
1985 MY*					
4-cylinder	23.8	0	35.9	0	1.8
6-cylinder	26.8	0	0	0	11.7
ALL	50.6	0	35.9	0	13.5
1987 MY projected**					
4-cylinder	21.2	0	38.5	0	1.8
6-cylinder	26.8	0	0	0	11.77
ALL	48.0	0	38.5	0	13.5
1988 MY projected**					
4-cylinder	0	0	59.7	0	1.8
6-cylinder	0	0	26.8	0	11.7
ALL	0	0	86.5	0	13.5
$LDGT_2$:					
1985 MY*					
6-cylinder	3.3	0	0	0	18.9
8-cylinder	34.0	0.8	18.4	8.7	15.9
ALL	37.3	0.8	18.4	8.7	34.8
1987 MY projected**					
6-cylinder	3.3	0	0	0	18.9
8-cylinder	15.6	0.8	36.8	8.7	15.9
ALL	18.9	0.8	36.8	8.7	34.8
1988 MY projected**					
6-cylinder	0	0	3.3	0	18.9
8-cylinder	0	0	53.2	0	24.6
ALL	0	0	56.5	0	43.5

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* Based on manufacturers' confidential sales projections:

** Based on manufacturers' confidential comments to the NPRM.

Table 3-2

Light-Duty Gasoline Trucks
Percent Technology Usage by Model Years for All LDGTs

		Percent Technology Used		
Model Year	No Catalyst	Oxidation Catalyst	Three-way Open-Loop	Three-way*** Closed-Loop
1982*	4.2	91.2	0.2	4.4
1983*	1.4	80.3	0.0	18.3
1984*	0.0	58.0	11.0	31.0
1985*	0.0	43.3	4.9	51.8
1987**	0.0	36.9	3.6	59.5
1988 and later**	0.0	0.0	0.0	100.0

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* Based on confidential sales projections provided by manufacturers as part of the certification process.

** Projected based on confidential manufacturer comments to the NPRM.

*** Also includes three-way closed-loop plus oxidation catalyst systems (see Table 3-1).

Table 3-3

Light Duty Gasoline Truck
Emission Control System Hardware
Cost Per Vehicle With New Technology

Technology Change		Engine Size		
From	To	4CYL	6CYL	8CYL
Oxidation	Three-way Closed Loop	$106	$133	$157
Three-way	Three-way Closed Loop	--	--	$65

- The 8-cylinder engines also have some open-loop three-way systems, which will go to closed-loop in model year 1988. Of the $LDGT_2$ market, 9.5 percent will need new closed-loop control (8.7 percent from three-way plus oxidation catalysts to three-way closed-loop plus oxidation catalysts, and 0.8 percent from three-way to three-way closed-loop catalysts) at $65 per vehicle, which makes this portion of the 8-cylinder contribution: 0.095 X $65 = $6.18

- The remainder of the $LDGT_2$ market, 71.6 percent, already will have three-way closed-loop catalyst or three-way closed-loop plus oxidation catalyst systems in place by model year 1987, and thus will incur no costs.

- The average hardware cost per $LDGT_2$ in the fleet is the sum of the 6- and 8-cylinder contributions and is: $4.43 + $24.49 + $6.18 = $35.10, or about $35.

- This cost, when distributed only over those vehicles requiring new technology, is about $123 per $LDGT_2$.

The average per vehicle hardware costs of $58 for $LDGT_1$s and $35 for $LDGT_2$s derived above include the total costs for hardware components added (three-way catalysts, feedback carburetor modifications, and/or closed-loop control), with a credit for those components removed (oxidation catalysts and/or open-loop control), averaged over the entire fleet of vehicles in that LDGT category. However, the complete cost of such hardware should not be applied solely to the more stringent NOx standard, since the manufacturer also derives other significant benefit from its application. This is indicated by the fact that manufacturers have already converted much of their fleet from oxidation to three-way catalyst systems, and have stated in their comments that they plan to continue this trend, even though it is not necessary from an emissions control standpoint under the current 2.3 g/mi NOx standard. The application of this more costly technology prior to the implementation of the stricter standard clearly indicates benefits to the manufacturer, which include improved fuel economy and driveability as well as parts consistency with their light-duty vehicles. This parts consistency leads to greater economic efficiency and lower total costs. It is difficult to quantify the precise value of these benefits to the manufacturer; however, it is clear that they are significant. Absent any more precise information, EPA has applied 50 percent of the costs to the implementation of the standard, and 50 percent to the other benefits which will be

- It is projected that 48 percent of all LDGT$_1$s will require technology changes between 1987 and 1988.

- First, 4-cylinder LDGT$_1$s, representing 21.2 percent of all LDGT$_1$ sales, are converted from oxidation catalysts to three-way closed-loop catalysts. At $106 per conversion, the contribution of 4-cylinder engines to the LDGT$_1$ hardware cost is: 0.212 X $106 = $22.47

- Six cylinder LDGT$_1$s, representing 26.8 percent of all LDGT$_1$s, are changed from oxidation catalysts to three-way closed-loop catalysts, at $133 per vehicle. The 6-cylinder contribution to the LDGT$_1$ hardware cost is then: 0.268 X $133 = $35.64

- The remainder of the LDGT$_1$ market, 52 percent, is projected to already have the required technology (38.5 percent three-way closed-loop catalysts and 13.5 percent three-way closed-loop plus oxidation catalysts) in place for the 1987 model year. (In fact, most of these vehicles, 49.4 percent of the market, already have the hardware on the 1985 model year vehicles.) No costs are incurred for these vehicles.

- The average hardware cost per LDGT$_1$ in the fleet is the sum of the contributions by the 4- and 6-cylinder engines and is: $22.47 + $35.64 = $58.11 or approximately $58.

- This cost is $121 per vehicle when applied only to those LDGT$_1$s requiring new technology in model year 1988.

The same methodology can be used for LDGT$_2$s:

- For the 3.3 percent of LDGT$_2$s which are 6-cylinder engines and which are converted from oxidation catalyst to three-way closed-loop catalyst technology, the cost is $133 per vehicle, which results in a contribution of: 0.033 X $133 = $4.43

- For the 15.6 percent of the LDGT$_2$ market which are 8-cylinder engines with oxidation catalysts and which will be changed to three-way closed-loop catalyst systems at a cost of $157, the resulting 8-cylinder contribution is: 0.156 X $157 = $24.49

- The 8-cylinder engines also have some open-loop three-way systems, which will go to closed-loop in model year 1988. Of the $LDGT_2$ market, 9.5 percent will need new closed-loop control (8.7 percent from three-way plus oxidation catalysts to three-way closed-loop plus oxidation catalysts, and 0.8 percent from three-way to three-way closed-loop catalysts) at $65 per vehicle, which makes this portion of the 8-cylinder contribution: 0.095 X $65 = $6.18

- The remainder of the $LDGT_2$ market, 71.6 percent, already will have three-way closed-loop catalyst or three-way closed-loop plus oxidation catalyst systems in place by model year 1987, and thus will incur no costs.

- The average hardware cost per $LDGT_2$ in the fleet is the sum of the 6- and 8-cylinder contributions and is: $4.43 + $24.49 + $6.18 = $35.10, or about $35.

- This cost, when distributed only over those vehicles requiring new technology, is about $123 per $LDGT_2$.

The average per vehicle hardware costs of $58 for $LDGT_1$s and $35 for $LDGT_2$s derived above include the total costs for hardware components added (three-way catalysts, feedback carburetor modifications, and/or closed-loop control), with a credit for those components removed (oxidation catalysts and/or open-loop control), averaged over the entire fleet of vehicles in that LDGT category. However, the complete cost of such hardware should not be applied solely to the more stringent NOx standard, since the manufacturer also derives other significant benefit from its application. This is indicated by the fact that manufacturers have already converted much of their fleet from oxidation to three-way catalyst systems, and have stated in their comments that they plan to continue this trend, even though it is not necessary from an emissions control standpoint under the current 2.3 g/mi NOx standard. The application of this more costly technology prior to the implementation of the stricter standard clearly indicates benefits to the manufacturer, which include improved fuel economy and driveability as well as parts consistency with their light-duty vehicles. This parts consistency leads to greater economic efficiency and lower total costs. It is difficult to quantify the precise value of these benefits to the manufacturer; however, it is clear that they are significant. Absent any more precise information, EPA has applied 50 percent of the costs to the implementation of the standard, and 50 percent to the other benefits which will be derived from application of the new technology. That is, the average per vehicle hardware cost for the 1.2/1.7 standards is \$29 per $LDGT_1$, and \$18 per $LDGT_2$.

These LDGT costs can be combined with LDDT costs to give an overall LDT sales weighted hardware cost per vehicle. No comments specifically addressed the issue of LDDT hardware costs. Therefore, the costs developed in the Draft RIA will be used here. These LDDT costs are \$20 per vehicle requiring the first time application of EGR, or $LDDT_1$s, and \$42 per vehicle needing a conversion to electronically-controlled EGR from current EGR, or $LDDT_2$s; details of their derivation can be seen in the Draft RIA.

The average hardware cost per LDT can now be calculated using the LDGT costs developed above and the LDDT costs presented above. Sales weighting these costs will give the average per vehicle cost of the proposed LDT NOx standard. Table 3-4 presents projected sales of gasoline and diesel LDTs, based upon total sales from the Draft RIA and gasoline and diesel sales fractions from Chapter 4.

Further subdivisions between LDT_1 and LDT_2 were made utilizing the sales projections provided by manufacturers during certification for the 1984 and 1985 model years. The 1984 projections showed $LDGT_1$s with about 75 percent of the LDGT market in 1984, while the 1985 model year projections indicated a rise in sales of larger LDGTs, so that $LDGT_1$s shared the market roughly equally with $LDGT_2$s. This rise is against the trend of increasingly greater sales fractions of smaller vehicles seen in the several preceding model years, and is probably attributable to the easing of gasoline prices and general strengthening of the economy. It is assumed that, in the future, percentages of $LDGT_1$s in the LDGT market will fall between the values seen in model year 1984 and 1985 sales projections, i.e., at about 62 percent. The diesels are assumed to continue their $LDDT_1/LDDT_2$ split as in the model year 1984 and model year 1985 projections: 33 percent $LDDT_1$ and 67 percent $LDDT_2$.

These values when combined with the sales projections presented in Table 3-4 give total sales per LDT type for model years 1988 through 1992 as shown in Table 3-5.

Combining the sales values with the previously calculated costs results in an average per vehicle cost of (.52)(\$29) + (.32)(\$18) + (.05)(\$20) + (.11)(\$42) = \$26.46, or about \$26 for the LDT manufacturer to install the necessary hardware for compliance with the 1.2/1.7 g/mi NOx standard.

Table 3-4

Projected Light-Duty Truck Sales (in thousands)*

Years	Gasoline**	Diesel**	Total
1988	3,070	420	3,490
1989	3,100	460	3,560
1990	3,010	530	3,540
1991	2,980	690	3,670
1992	2,890	850	3,740
Totals	15,050	2,950	18,000

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* Total sales projections for 1988-1991 were drawn from the Draft RIA. 1992 projections were determined using the same methodology.

** Gasoline and diesel splits were taken from Chapter 4.

Table 3-5

Projected Market Share by LDT Subcategory, 1988-1992 Model Years

LDT Subcategory	Sales (thousands)	Market Share	Hardware Cost/Vehicle
$LDGT_1$	9,330	52%	$29
$LDGT_2$	5,720	32%	$18
$LDDT_1$	970	5%	$20
$LDDT_2$	1,980	11%	$42
Total	18,000	100%	$26*

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* Sales-weighted average.

iii. Total Cost to Manufacturers

Total manufacturer cost of compliance with the LDT NOx standard is based on hardware costs for sales projected for the 5-year period beginning with the first model year of the standard plus the total costs for RD&T. These costs are then discounted at 10 percent to the first year of the standard (1988) so that costs over the years of interest can be expressed in equivalent dollars. It is projected that RD&T costs will be incurred as in Table 3-6, shown in both undiscounted and discounted form. Hardware cost is spent according to sales, and is shown in Table 3-7. Total manufacturer costs are combined in Table 3-8; as can be seen, the net present value of the manufacturer cost in 1988 is $426,820,000.

b. Cost to Users

i. First Cost

The added cost to manufacturers for RD&T and emission control system hardware is expected to be passed on to the purchasers of LDTs. The amount a manufacturer must increase the price of its vehicles to recover its expenses depends on the timing of the costs, the revenues from sales, and the cost of capital to the manufacturer. It is expected that manufacturers will increase the vehicle prices to recover their pre-production investment in five model years, 1988-92. When RD&T costs are amortized over the vehicle sales, the cost is $2 per LDT. The first price increase of a vehicle would be the sum of this cost plus the cost of the hardware, $26. The average first price increase for an LDT sold between 1988 and 1992 is thus $28; this is a sales-weighted average of the $LDGT_1$ cost of $31, $LDGT_2$ cost of $20, $LDDT_1$ cost of $22, and the $LDDT_2$ cost of $44, including the $2 per vehicle for discounted RD&T.

These costs can also be expressed in terms of only those vehicles requiring new technology rather than as an average per vehicle cost by adding RD&T apportioned over the applicable vehicles ($3 per LDGT and $2 per LDDT with new technology) to the hardware required for that vehicle as shown in Table 3-3. These costs are summarized in Table 3-9.

ii. Fuel Economy

Fuel economy impact was determined to be small, as discussed in Chapter 2, Technological Feasibility. For those vehicles with existing three-way systems which already meet the standards, no fuel economy penalty should be experienced, while those converting from oxidation to three-way catalyst systems

Table 3-6

LDT RD&T Costs for 1.2/1.7 NOx

	Undiscounted			Discounted		
	Non-Cert Costs	Cert Costs	Total	Non-Cert Costs	Cert	Total
1986	$9,000K	$1,900K	$10,900K	$10,890K	$2,299K	$13,189K
1987	$2,870K	$13,200K	$16,070K	$3,157K	$14,520K	$17,677K
	$11,870K	$15,100K	$26,970K	$14,047K	$16,819K	$30,866K

Table 3-7

LDT Hardware Costs for 1.2/1.7 NOx

	Undiscounted	Discounted*
1988	$92,350K	$92,350K
1989	94,200K	85,640K
1990	93,670K	77,410K
1991	97,110K	72,960K
1992	98,960K	67,590K
TOTAL	$476,290K	$395,950K

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* Discounted at 10 percent to 1988.

Table 3-8

Total LDT Manufacturer Cost

	Undiscounted		Discounted*	
	RD&T	Hardware	RD&T	Hardware
1986	$10,900K	--	$13,190K	--
1987	$16,070K	--	$17,680K	--
1988	--	$92,350K	--	$92,350K
1989	--	$94,200K	--	$85,640K
1990	--	$93,670K	--	$77,410K
1991	--	$97,110K	--	$72,960K
1992	--	$98,960K	--	$67,590K
	$26,970K	$476,290K	$30,870K	$395,950K
TOTAL	$503,260K		$426,820K	

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* Discounted at 10 percent to 1988.

Table 3-9

Light-Duty Trucks First Price Increases

Vehicles Requiring New Technology		
LDGT:		
4-Cylinder	Three-way Closed Loop from Oxidation Catalyst ($LDGT_1$)	\$109
6-Cylinder	Three-Way Closed-Loop From Oxidation Catalyst ($LDGT_{1\ \&\ 2}$)	\$136
8-Cylinder	Three-Way Closed-Loop From Oxidation Catalyst ($LDGT_2$)	\$160
8-Cylinder	Three-Way Closed-Loop From Three Way Open Loop ($LDGT_2$)	\$ 68
LDDT:		
$LDDT_1$	First Time Application of EGR	\$ 22
$LDDT_2$	Electronically Controlled EGR from EGR	\$ 44

Average for All Vehicles	
$LDGT_1$	\$ 31
$LDGT_2$	\$ 20
$LDDT_1$	\$ 22
$LDDT_2$	\$ 44
All LDTs	\$ 28

may experience a gain of up to 8 percent. This was seen in comparisons of 1985 certification data of matched pairs of Federal and California vehicles. For fuel economy changes which may occur, the costs remain as in the Draft RIA at $51 for LDGTs and $41 for LDDTs lifetime cost per affected vehicle per one percent change in fuel economy, either greater or less. When apportioned over all vehicles, the cost is $21 per LDGT and $41 per LDDT, or $24 per LDT per one percent change in fuel economy. It is expected that on a fleetwide basis there may be a slight gain in fuel economy; however, for costing no fuel gain was included.

iii. Total Cost to Users

To summarize, purchasers of LDTs can expect to pay an average of $28 more for 1988 model year LDTs for the emission control improvements as compared to 1987 LDTs. In the case of fuel economy increases or decreases, LDGT users can expect a $51 change in lifetime operating cost per one percent change in fuel economy, while LDDT users can expect a $41 change. A slight gain in fuel economy is expected, but is not included in total cost.

2. Aggregate Costs for the 1988 LDT NOx Standard

The aggregate cost to the nation of complying with the 1988 Federal LDT NOx emission regulations consists of the sum of fixed costs for RD&T and new emission control hardware. No changes in maintenance or fuel economy costs are expected. These costs are calculated based on sales projections for the 5-year period following introduction of the standard. These sales projections were shown in Table 3-4.

The various costs associated with this rulemaking action will occur in different periods. In order to make all costs comparable, the present value at the start of 1988 has been calculated based on a discount rate of 10 percent. The calculations were shown earlier in Table 3-8. The aggregate cost of complying with the new regulations for the 5-year period is estimated to be equivalent to a lump sum investment of about $427 million (1984 dollars) made at the start of 1988. When amortized over the projected sales for the five-year period, the value is $28 per vehicle at the time of purchase.

B. HDGE NOx Standards

Comments on the costs of the proposed HDGE NOx standards were received from two of the three major manufacturers of HDGEs and were not highly detailed. Chrysler gave a cost estimate only for the later standard, with no estimate for a fuel economy penalty. General Motors stated that, "the predominant HDGE costs associated with the more stringent NOx standards proposed by EPA would be an increase in fuel consumption." Ford comments did not discuss the costs of the standard. Therefore, any cost revisions below are based on a reanalysis of the control technology necessary, which the manufacturers' comments did discuss, rather than on concerns for cost estimates for specific components of the control technology.

Before beginning this reanalysis of the costs to comply with the 1988 and 1991 HDGE NOx standards, a brief discussion of HDGE certification data and options and potential certification approaches is necessary. First, as of February 1985, the three major HDGE manufacturers had certified a total of seven families. This is a decrease of eight families from 1984, brought about by IH leaving the market completely, Chrysler dropping one family, and GM and Ford each combining two families which were previously separate. However, due to the split class HDGE emission standards beginning in 1987, the number of HDGE families is projected to increase from 7 to 10 or 11 even though no new engine offerings are expected. For simplicity, and since all HDGEs will have to meet the same NOx standards, this analysis will assume that HDGE sales are spread evenly among the 11 families. This allows fixed costs to be assigned on a per family basis and spread over the entire fleet, without having to assign specific fixed costs to specific families for the sake of production-weighting the fixed cost impacts. As will be seen later, in the long term this introduces no error into the per vehicle cost.

Second, it is worth noting that beginning in 1987, manufacturers may exercise the option to certify their HDGVs of up to 10,000 lb GVW as LDTs. While this option also exists for the 1988 model year, this analysis does not evaluate that possibility. Presumably it would be more expensive on a per engine basis to meet the LDT NOx standard (probably requiring a three-way catalyst with closed-loop control) than it would be to meet the 1988 or 1991 HDGE standards. Therefore, if manufacturers choose to exercise this option in 1988, it would be based on their belief that other perceived or intangible benefits are worth any extra costs.

Third, any analysis of costs to meet the 1988 or 1991 HDGE NOx standards must be placed in the proper context by reviewing current HDGE NOx certification levels. The certification data presented in the HDGE technological feasibility analysis indicates that none of the families certified in 1985 meet the 1988 6.0 g/BHP-hr NOx standard, even though two configurations within these families do meet the 1988 standards and one of these two configurations meets the 1991 standard. For purposes of cost estimation, this analysis will assume that no current HDGE families meet the 1988 NOx standard of 6.0 g/BHP-hr. However, several will be very close.

1. 1988 NOx

a. Cost to HDGE Manufacturers

i. Fixed Costs

As noted above, no comments specifically addressed the issue of manufacturers' cost of the intermediate HDGE NOx standard. However, a reanalysis of cost has been done to reflect changes in the EPA projection of the control technology necessary to meet the standard, as discussed in Chapter 2, Technological Feasibility. These new cost estimates are outlined below.

The costs originally estimated for RD&T included recalibration of the fuel, ignition, and EGR systems as well as certification costs. In total, these recalibrations amounted to $39,600 per engine family based on three calibration combinations at six person-weeks of effort each. Certification costs in the Draft RIA were $192,170 per engine family, based on one durability and three data engines per family.

The final cost estimate includes these costs, plus costs for evaluation and recalibration for improved secondary air management, redesign of the combustion chamber, and emission-related improvements of the intake manifold. Secondary air management recalibration is expected to require about the same level of effort as the fuel, EGR, or ignition system, or $13,200 per engine family. Redesign and testing of the combustion chamber is expected to consist of a redesign of the cylinder head and was estimated in the Draft RIA for the proposed 4.0 standard to cost $306,900 per engine family, (including a 10 percent contingency factor). This value is used here. Finally, enhancement of the intake manifold is estimated to require about five times the level of effort of any of the above recalibrations, an amount of $66,000 per engine family.

As was discussed above, it is now projected that the major manufacturers will certify a total of 11 HDGE families in 1988. The three tasks originally presented in the Draft RIA are expected to be necessary for all 11 engine families. Total cost is thus $580,800 for recalibration of EGR, fuel, and ignition systems.

Of the 11 engine families receiving this recalibration, 8 are expected to be able to meet the 6.0 standard without additional changes. This is based on a review of current NOx certification levels which indicates only three families have NOx emission levels above 8.0 g/BHP-hr. The other three HDGE families may require some or all of the additional work listed above: secondary air recalibration, combustion chamber redesign, and intake manifold improvement. As given in the Draft RIA, RD&T costs for applying these improvements to each of the remaining engine families are $13,200 for the secondary air, $306,900 for the combustion chamber, and $66,000 for the intake manifold for a total of $386,100 per family. Assuming that all three families do all the work, this totals an additional $1,158,300.

Certification must be conducted for all 11 engine families. Using the $192,170 certification cost per family presented in the Draft RIA, certification costs total $2,113,870. The total fixed costs to meet the 1988 HDGE NOx standard is the sum of the development and certification costs or about $3,708,000. The separate components of these costs are detailed in Table 3-10.

ii. Variable Cost

EGR is the major NOx emission control component expected on HDGEs. A review of the 1985 certification records indicates that six of the seven HDGE families currently have EGR installed. One family, representing about 4 percent of sales, would have to install EGR to meet the 1988 HDGE NOx standard. In a 1980 study completed for EPA, HDGE EGR was estimated to cost $9.36 at the vendor level (1977 dollars).[10] When adjusted for inflation to 1985 dollars using the new car CPI (1.43) and accounting for manufacturer and dealer overhead and profit (1.29),[9] HDGE EGR is estimated to have a retail price equivalent of $17.27. When spread over all the vehicles in the fleet, this averages $0.69 per vehicle.

In addition the recalibration discussion above indicated that 3 families may need additional work for combustion chamber modifications and intake manifold improvements. Redesigned hardware may be necessary for the three HDGE families needing this work. In the long term, the redesigned parts could presumably cost the same as those being replaced, but a conservative approach is taken and $10 is assigned per redesigned engine. When this cost for work on three engine families is spread over all HDGEs, the hardware cost per redesigned engine due to the 6.0 standard is $2.73. When the EGR cost is added to the redesigned component cost, the total hardware cost sums to $3.42 per HDGE.

Table 3-10

Summary of 1988 HDGV NOx RD&T Costs

	Category	Families Affected	Cost per Family	Total
1.	Fuel, ingition and EGR recalibration	11	$39,600	$435,600
2.	Secondary air management, combustion chamber redesign, and intake manifold mods.	3	$386,100	$1,158,300
3.	Certification	11	$192,170	$2,113,870
				$3,707,770

iii. Total Manufacturer Cost

The total manufacturer cost of the 6.0 HDGE NOx standard is the sum of the RD&T cost and the hardware cost for the engines produced in the three model years immediately following introduction of the standard, all discounted at 10 percent to 1988. Projected sales have been updated to reflect information in Reference 3, and are presented in Table 3-11. These sales figures have been used to generate the total manufacturer hardware costs, and are presented together with total RD&T costs in Table 3-12. Manufacturer costs are shown to be $7,671,000 undiscounted and $7,869,000 discounted.

b. Cost to Users

i. First Cost

Manufacturers must recover their costs by increasing the first price of vehicles equipped with HDGEs. It is expected that manufacturers face a 10 percent cost of capital and recover their RD&T costs in the three model years immediately following introduction of the standard, 1988-90. The discounted RD&T costs amortized over the engines projected to be sold in those three model years results in a cost per engine of $4.02, or about $4. The sum of the engine share of RD&T cost and the hardware cost ($3.42) is the first price increase. Averaged over all model year 1988-90 HDGES, the total is $7.44, or about $7 per engine.

ii. Operating Costs

As described in the technological feasibility analysis, the fuel economy impact of the 6.0 NOx standard is expected to be negligible for HDGEs. Since only engine recalibrations and component redesigns will be used to achieve the required emission reductions, maintenance should not be affected by this standard.

iii. Total User Cost

The total cost to the user is simply the first price increase of approximately $7 per vehicle equipped with an HDGE. Operating costs are not expected to change.

2. Total Manufacturer and User Costs for the 1988 Standard

a. Manufacturer Cost

The total manufacturer cost of compliance for the 1988 HDGE NOx standard of 6.0 g/BHP-hr for the three model years

Table 3-11

Projected HDE Sales (thousands)

	Gas	Diesel	Total
1988	389	338	727
1989	386	353	739
1990	384	367	751
1991	381	382	763
1992	379	397	776
1993	381	403	784
1994	383	409	792
1995	384	416	800
1996	385	423	808
1997	388	429	817
1998	392	433	825
1999	396	437	833

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* Based on information presented in Reference 3.

Table 3-12

HDGE Manufacturer Costs for 1988 NOx Standard

	Undiscounted		Discounted*	
	RD&T	Hardware	RD&T	Hardware
1986**	$1,594K	-	$1,929K	-
1987***	2,114K	-	2,325K	-
1988	-	$1,330K	-	$1,330K
1989	-	1,320K	-	1,200K
1990	-	1,313K	-	1,085K
	$3,708K	$3,963K	$4,254K	$3,615K
Total	$7,671K		7,869K	

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* 10 percent to 1988.
** Research and development costs.
*** Certification costs.

1988-90 is the sum of fixed and variable costs developed above, and is about $7.7 million undiscounted or $7.9 million discounted at 10 percent to the year of the standard.

b. User Cost

The user cost is the sum of the first price increase developed above and any change in operating costs due to the standard. No operating cost increases are expected, so that the average cost to the user of a model year 1988-90 vehicle with a HDGE is about $7.

3. 1991 NOx

a. Cost to Manufacturer

EPA received only one comment concerning the cost estimate per HDGE due to the proposed 4.0 NOx standard. Chrysler estimated a cost of $180 for reduction from 6.0 to 4.1 g/BHP-hr, compared to the estimate in the NPRM of $18. However, Chrysler's comment did not detail the technology which would cause this price increase, nor did it indicate the amount of research, overhead and markup contained in the estimate. It is therefore difficult to determine to what extent the difference is based on actual differences between EPA and Chrysler estimates of specific costs, and to what extent it is due to differences in assumptions in areas such as technological approach, mark-up, vehicles over which costs are apportioned, etc.

Nevertheless, absent any detailed comment, EPA has re-evaluated the cost of the 1991 HDGE NOx standard based on the revision of the HDGE NOx portion of the technological feasibility analysis.

i. Fixed Cost

The cost analysis for the proposed 4.0 HDGE NOx standard contained in the Draft RIA included RD&T costs for the recalibration of the fuel, EGR, and ignition systems, combustion chamber modifications, and for certification. The final cost analysis for the 1991 HDGE NOx standard includes RD&T costs in these areas plus others for improvement of secondary air management and intake manifold modifications for those HDGE families not already receiving these changes. These costs are allocated as described below. The per family cost to accomplish each of these tasks is the same as allocated for 1988. For convenience, these costs are shown again in Table 3-13.

Table 3-13

RD&T Costs per HDGE Family

	Tasks	Costs per Family
1.	Fuel, ignition and EGR recalibration	$39,600
2.	Secondary air management	$13,200
3.	Combustion chamber redesign	$306,900
4.	Intake manifold modifications	$66,000
5.	Certification	$192,170

First, costs are again allocated to each HDGE family for further fuel, ignition, and EGR recalibration work. However, this is probably conservative since it is reasonable to expect that some families will be able to meet the 1991 NOx standard with only minor changes to 1988-90 calibrations.

Second, further costs for the more significant changes (secondary air management, combustion chamber redesign, and intake manifold modifications) are now allocated for these eight families not receiving these changes in meeting the 1988 standard. This is also conservative, since it is unlikely that all eight families would require all three of the more significant changes. Thus, as is shown in Table 3-14, recalibration work for all 11 families totals to $435,600 and other more significant changes for the remaining eight families totals to $3,088,800.

Third, certification costs are once again appropriated for all 11 families at a total cost of $2,113,870. Once again, this is conservative, since it is likely that some families will be able to gain 1991 certification through a running change in lieu of full certification.

As shown in Table 3-14 when the work is allocated as discussed above and summed, RD&T costs total $5,638,000 (undiscounted).

ii. Variable Cost

As was discussed above, redesigned hardware may be necessary for the combustion chamber and the intake manifold modifications, and was conservatively estimated above to cost $10 per affected engine. For the 5.0 standard, 8 of the 11 HDGE families will require this hardware. Spreading this cost evenly over all HDGEs, the average cost per engine is $7.27.

iii. Total Manufacturer Cost

The total manufacturer cost, including RD&T and hardware, sums to $13,933,000 undiscounted and $14,153,000 when discounted at 10 percent to 1991. This includes the RD&T costs developed above and the costs for redesigned hardware on model year 1991-93 engines. The stream of costs, both undiscounted and discounted, is shown in Table 3-15.

b. Costs to Users

i. First Cost

The incremental increase in the first price of a 1991 HDGV over a similar 1990 HDGV can best be presented as the average

Table 3-14

Summary of 1991 HDGE NOx RD&T Costs

	Category	Families Affected	Cost per Family	Total
1.	Fuel, ingition and EGR recalibration	11	$39,600	$435,600
2.	Secondary air management, combustion chamber redesign, and intake manifold mods.	8	$386,100	$3,088,800
3.	Certification	11	$192,170	$2,113,870
				$5,638,270

Table 3-15

HDGE Manufacturer Costs for 1991 NOx Standard

	Undiscounted		Discounted*	
	RD&T	Hardware	RD&T	Hardware
1989**	3,524K	-	$4,264K	-
1990***	2,114K	-	2,325K	-
1991	-	2,770K	-	2,770K
1992	-	2,755K	-	2,505K
1993	-	2,770K	-	2,289K
	$5,638K	$8,295K	$6,589K	$7,564K
Total	$13,933K		$14,153K	

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* 10 percent to 1991.
** Research and development costs.
*** Certification costs.

first price increase expected if costs are spread over all HDGEs. If RD&T costs are amortized over three years of sales (1991-93) at a 10 percent cost of capital, the average per engine increase attributable to RD&T equals $6.33. This added to a fleet average hardware cost of $7.27 gives a short term average first price increase of $13.60 for the 1991 NOx standard. In the long term this cost drops to about $7.

ii. Operating Costs

As is discussed in the technological feasibility analysis, no significant fuel economy impact is expected for HDGEs due to the 5.0 standard. Therefore, fuel costs will not be affected. Increased maintenance is not expected as a result of meeting the 1991 HDGE NOx standard, so maintenance costs should not change.

iii. Total User Cost

The total user cost of the 1991 standard is simply the first cost increase, averaging $13.60 over the cost of a model year 1990 vehicle equipped with an HDGE. No increases in operating costs are expected.

4. Total Manufacturer and User Cost for the 1991 Standard

a. Manufacturer Cost

The total manufacturer cost of compliance for the 1991 HDGE NOx standard of 5.0 g/BHP-hr for the three model years 1991-93 is the sum of fixed and variable costs developed above, and is about $13.6 million undiscounted or $14.2 million discounted at 10 percent to the year of the standard.

b. User Cost

The user cost is the sum of the first price increase developed above and any change in operating costs due to the standard. No operating cost increases are expected, so that the average cost increase to the user of a model year 1991-93 vehicle with a HDGE is $13.60. After RD&T costs are amortized, the first price increase will drop to about $7 per HDGV.

C. HDDE NOx and Particulate Standards

Specific comments on the proposed HDDE NOx standards were received from five manufacturers -- Cummins, Ford, General Motors, International Harvester, and Mack, as well as from the Department of Energy, the Engine Manufacturers Association, and the American Trucking Association. All commented either that hardware costs were substantially higher or fuel economy losses considerably greater, or both, than those estimated by EPA. In general, detailed derivations of the costs were not given in the comments, and EPA's derivation approach was not challenged. However, in one case a comparison of assumptions was made which detailed the reasons for fuel economy cost estimate differences without investigating the relative merit of the two methods.

The comments have prompted revised analyses of manufacturer cost estimates by EPA. In the case of RD&T, costs are based on the number of engine families which will require the work; at this time, family-specific data on HDDEs is not available. Therefore, EPA can only estimate the number of families which will require RD&T allocations based on general manufacturer comments. For hardware costs, those components which were not costed by Rath & Strong[1] were estimated by EPA in the Draft RIA; again, they are updated here based on general manufacturer comments. These estimates are retail price equivalent (RPE) costs. The detailed reanalysis is provided in the following sections.

1. 1988 NOx Standard

a. Cost to HDDE Manufacturers

Hardware changes deemed necessary for engines to meet the 6.0 g/BHP-hr NOx standard as outlined in the Draft RIA included injection timing retard and the addition of aftercooling to non-aftercooled turbocharged engines. In comparison to this, Ford outlined hardware plans of improved fuel injection systems, variable injection timing, and turbocharging on all engines, as well as charge air cooling on some. Cummins listed variable injection timing, low temperature aftercooling, increased fuel injection pressure, combustion chamber modifications, and an electronically controlled fuel system, while International Harvester listed engine cooling system changes, air-to-air aftercooling, and electronically controlled fuel systems. The dissimilarities in these lists of hardware changes contributed to the difference in cost estimates between manufactures and EPA; they also prompted a revision of development tasks and hardware in the EPA analysis, which is presented later.

The costs presented by manufacturers for HDDE 6.0 g/BHP-hr NOx control are compared to EPA's projections as follows:

Retail Price Increase per HDDE, 6.0 NOx Standard

Draft Analysis	$16	HDDE average
	$78	HDDE with new technology
Cummins	$100-800	Depending on need for variable timing; including particulate control
Ford	$350	HDDE average, including particulate control
IH	$337	HDDE average

Ford's cost is an estimate of the consumer cost for the hardware changes described above, which are currently planned for model year 1987 in anticipation of more stringent NOx standards for that year. Cummins indicates "...an increase in estimated engine prices for the Cummins product line." The value given by International Harvester (IH) is a sales-weighted value of going from 10.7 to 6.0 g/BHP-hr NOx based on the cost difference between present California and Federal IH engines. The California NOx standard is 5.1 g/BHP-hr.

The costs presented by manufacturers are clearly higher than those given by EPA, prompting the reanalysis which is included below; however, since the industry estimates do not give detailed breakdowns of components and costs, it is difficult to tell whether the values in the comments can be directly compared to the EPA estimates. For example, the industry estimates are presumably per engine requiring new technology, although this is not clearly stated; the EPA estimates presented in the NPRM are spread over all HDDEs, some of which are projected not to require the new hardware. Also, manufacturers, when indicating increase in "consumer cost", do not indicate which RD&T costs are included, nor the amount of dealer markup. From aggregate RD&T costs which were provided confidentially by some manufacturers, it appears that ongoing basic research costs are included, rather than only those costs which arise from research directly applicable to this standard, as in the EPA analysis.

Dealer markup is presumably higher in the industry analysis than in EPA's analysis; EPA bases its markup on the idea that the dealer will incur no costs due to the standard except for the interest that must be paid on the higher cost of the inventory before it is liquidated; this interest is included in the EPA markup value. Using this method, the dealer will receive no profit due to the standard, but will not take a loss either. On the other hand, if the manufacturers are including their usual dealer markup in their "consumer cost" estimates, the dealer is taking a profit from the standard; such dealer profit is not correctly applied to the cost of the standard.

Such differences in the analyses may partially explain the differences between EPA and manufacturer cost estimates, and create a situation where the values cannot be directly compared. Resolution of these potential differences is confounded by the fact that the development of the industry cost estimates is not documented in the comments, so that even the discussion above is only a conjecture as to what the cost values presented in the comments may actually represent.

Nevertheless, as part of its review of the technological feasibility of the 6.0 g/BHP-hr NOx standard, EPA has reevaluated the control technology needed to meet the standard. This in turn has led to a reanalysis and revision of the cost figures; this revision is discussed below.

i. Fixed Cost

The reanalysis of the RD&T and hardware costs necessary for HDDEs to comply with the 6.0 g/BHP-hr NOx standard includes the timing retard and addition of aftercooling as in the Draft RIA, plus additional RD&T and hardware costs of improved aftercooling, variable injection timing, and improved turbocharging. The number of HDDE families remains at 86, as in the Draft RIA.

Timing retard calibration evaluation was costed at $26,400 per engine family in the Draft RIA, based on three calibrations per engine family, 160 labor hours per calibration at a rate of $50 per hour, and a 10 percent contingency factor. This value has been increased to $132,000, five-fold the original, because an increased number of calibration evaluations would be necessary to optimize fuel economy and to deal with the larger number of approaches available for meeting the 6.0 g/BHP-hr standard. For 1986 engine families, RD&T comes to $11,352,000 for timing retard. The addition of aftercooling to 10 percent of the HDDE families (half of those turbocharged engines without aftercooling) remains as before, at $57,400 per engine family and a total of $494,000 based on six person-months of engineering and development work per family.

New to this analysis for the 6.0 standard is the improvement of aftercooling, which was previously believed to be necessary only for the 4.0 standard but is now added in response to manufacturer comments. This RD&T cost also remains the same as in the 4.0 portion of the Draft RIA, at $172,200 per family for air-to-air and $57,400 for air-to-liquid aftercooler systems. At a 50 percent application rate for each system for the 72 engine families expected to have aftercooling, the total cost is $8,266,000.

Variable injection timing (VIT) and improved turbocharging are also new to this analysis, and are each estimated to have RD&T costs of $95,700 per engine family; however, half of these costs are applied to the particulate standard, leaving $47,850 per family for each of the two tasks. This value is based on two designs per change, four person-months per design, and the usual $50 per hour and 10 percent contingency factor, as well as an additional 25 percent to account for the effort needed to optimize fuel economy. Assuming VIT and improved turbocharging will each be assigned to 50 percent of the 86 engine families, these costs are $2,058,000 per task, or $4,115,000.

Certification costs remain at $6,500,000 as presented in the Draft RIA. This includes dynamometer time and emission test costs for one durability and three data engines per engine family.

Total RD&T costs are then the sum of all these costs, or $30,738,000. This is comprised of $11,352,000 for timing calibration evaluations, $494,000 for the addition of aftercooling, $8,266,000 for the upgrading of current aftercooling systems, $4,115,000 for VIT/improved turbocharging and $6,500,000 for certification.

ii. Variable Cost

Hardware costs per engine have also increased. While costs for injection timing retard and addition of aftercooling remain, total hardware costs are increased due to the addition of improved aftercooling, variable timing, and improved turbocharging. The per engine hardware cost for HDDEs adding aftercooling capability remains at $61, with 10 percent of HDDEs being affected.

Improved aftercooling cost per engine also remains as originally in the Draft RIA for the proposed 4.0 standard, at $73 for conversion of an air-to-liquid to an air-to-air aftercooler, and $91 for upgrading of an existing air-to-liquid system. These costs, however, are now being allocated to some engines which will be built under the 6.0 standard, in response to manufacturer comments that some will need the technology for the earlier standard. The rate of application is such that half of all turbocharged engines (31 percent of all HDDEs) will employ new or upgraded aftercooler systems for the 1988 standard. One-third of this 31 percent, or 10 percent of the total, is comprised of HDDEs getting air-to-liquid aftercooling for the first time as described above. Of the remaining 21 percent, 16 percent will convert to improved air-to-liquid aftercooling and 5 percent will convert to air-to-air aftercooling. These costs average to $87 for each vehicle converting to improved aftercooling, and $18 when applied to all HDDEs.

The incremental cost of electronically-controlled variable injection timing is estimated at $25 per engine, and is applied to half of the engines, with half of the cost charged to the particulate standard. As noted above, this is an EPA estimate based on manufacturer comments to the NPRM.

Improved turbocharging is estimated to cost $5 per engine as in the Draft RIA, and would apply to 50 percent of all turbocharged HDDEs (31 percent of all HDDEs). Half of this cost would be applied to the particulate standard.

The sum of these costs on a fleetwide average basis is about $32 per HDDE. When applied only to engines requiring the new technology, and the average hardware cost for the 6.0 g/BHP-hr NOx standard would be $93 per engine.

iii. Total Manufacturer Cost

Total RD&T and hardware costs must be discounted at 10 percent to the year of the standard, 1988, in order to represent actual manufacturer cost. It is reasonable to expect that RD&T expenditures will be made in the two years immediately preceding the year of the new standard. The RD&T costs described above are summed in Table 3-16, and presented in undiscounted and discounted form. Hardware costs are allocated according to sales projections, which have been updated due to new information[3] and were shown in Table 3-11. Using these sales projections and the average cost per HDDE developed above results in the distribution of hardware costs shown in Table 3-17, in both undiscounted and discounted form. Since the 6.0 g/BHP-hr NOx would only apply through 1990, the hardware costs are presented and summed for only three model years of HDDE sales. Manufacturer hardware costs sum to $34 million dollars undiscounted and $31 million discounted.

These manufacturer costs for RD&T and hardware are summarized and presented on an annual basis in Table 3-18. This analysis results in a total undiscounted manufacturer cost of about $64.4 million and a discounted cost of about $66.4 million.

Table 3-16

HDDE RD&T Costs for 6.0 NOx

	Undiscounted			Discounted*		
	Non-Cert. Costs	Cert. Costs	Total	Non-Cert. Costs	Cert. Costs	Total
1986	$17,000K	$1,000K	$18,000K	$20,570K	$1,210K	$21,780K
1987	$ 7,200K	$5,500K	$12,700K	$7,920K	$6,050K	$13,970K
TOTALS	$24,200K	$6,500K	$30,700K	$28,490K	$7,260K	$35,750K

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* Discounted at 10 percent to 1988.

Table 3-17

HDDE Hardware Costs for 1988 NOx Standard

	Undiscounted	Discounted*
1988	$10,753K	$10,753K
1989	11,228K	10,207K
1990	11,675K	9,649K
TOTAL	$33,656K	$30,609K

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* Discounted at 10 percent to 1988.

Table 3-18

HDDE Manufacturer Costs for 1988 NOx Standard

	Undiscounted		Discounted*	
	RD&T	Hardware	RD&T	Hardware
1986	$18,000K	--	$21,780K	--
1987	12,700K	--	$13,970K	--
1988	--	$10,753K	--	$10,753K
1989	--	11,228K	--	10,207K
1990	--	11,675K	--	9,649K
	$30,700K	$33,656K	$35,750K	$30,609K
TOTAL	$64,356K		$66,359K	

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* Discounted at 10 percent to 1988.

b. Cost to Users

i. First Cost

Increases in HDDE purchase price due to the 6.0 NOx standard are determined in the same manner as for the LDT standard, except that the capital costs (RD&T) are expected to be recovered in three rather than five model years due to the introduction of the second NOx standard in 1991. The average increase in first cost of HDDEs would consist of the sum of the discounted RD&T cost amortized over vehicle sales for model years 1988 through 1990 through plus the average per engine hardware cost. These costs can also be expressed per HDDE requiring new technology rather than as average per engine cost by adding the RD&T cost apportioned only over the affected vehicles to the cost of the hardware required. Costs using these two different approaches are presented below.

First, total discounted RD&T cost amortized over the total HDDE sales projected for model years 1988 through 1990 results in a cost of approximately $37 per vehicle. When this is added to the $32 average hardware cost developed above, the average first price increase is $69. When distributed only over those engines affected by the standard, the costs are $50 for RD&T and $93 for hardware, for a total of $143 for a vehicle receiving new technology.

ii. Fuel Economy

In Chapter 2, Technological Feasibility, it was estimated that fuel economy penalties associated with the 1988 model year NOx standard would be in the range of 0 to 2 percent in the short term. This penalty should tend to disappear by the time of implementation of the second standard, 1991, as part of a normal trend toward further engine and vehicle improvements. EPA has reevaluated the cost impact of these short-term fuel economy losses based on the comments received. This is presented below.

First, fuel economy estimates for 1988 HDDVs have been updated, and are derived from information in Reference 3. These estimates for LHDDEs, MHDDEs, and HHDDEs have been lowered to 15.1 mpg, 8.0 mpg, and 5.9 mpg respectively. This makes them closer to the Argonne National Laboratory estimates supplied in comments received from the Department of Energy (DOE) which compared EPA and ANL assumptions. These fuel economy values are combined with a fuel cost of $1.20 per gallon; ANL used $1.46 as the estimated average cost over the lifetime of the vehicle. However, since the price of diesel fuel has varied significantly in the recent past, and since fuel prices continue to be highly sensitive to the world political climate and, therefore, unpredictable, EPA has used $1.20/gal as representative of today's price without attempting to project future price increases.

Average annual mileages and lifetimes remain as in the Draft RIA, at 11,000 miles per year for 10 years, 30,000 miles per year for 9 years, and 65,000 miles per year for 8 years for LHDDEs, MHDDEs, and HHDDEs, respectively. These values include one rebuild for some of the MHDDEs and most of the HHDDEs, and are reasonable estimates of the actual lifetimes of these engines for fuel economy purposes. The useful life VMTs used by ANL do not involve any rebuilds, but EPA has found that the majority of the heavier HDDEs are not, in fact, retired after their initial useful life, and hence would continue to accrue fuel economy penalties. Therefore, EPA has included these higher lifetime values in calculating the lifetime fuel economy cost for the standard.

A 10 percent discount rate is employed with the values given above and the fuel economy estimates are sales weighted in arriving at the average cost per engine and total average lifetime cost. The sales fractions used are 35 percent LHDDE, 29 percent MHDDE, and 36 percent HHDDE, and are derived from information presented in Reference 3.

Using the fuel economy, fuel price, and vehicle/engine average lifetime miles and years it can be calculated that each one percent reduction in fuel economy corresponds to an annual increase in diesel fuel usage of 7.3 gallons for LHDDEs, 37.5 gallons for MHDDEs, and 110.2 gallons for HHDDEs. These increases in fuel usage correspond to lifetime discounted costs of $54 for LHDDEs, $259 for MHDDEs, and $705 for HHDDEs. Sales weighting these costs gives the average lifetime cost for a 1 percent change in fuel economy of $348 per affected engine.

Applying these average costs, the range in the fuel economy cost per engine which corresponds to the 0 to 2 percent change expected for model year 1988 vehicles for the 1988 HDDE NOx standard is $0 to $696. This value should drop to $0 before implementation of the 1991 standard.

iii. Maintenance

No increase or decrease in maintenance is expected as a result of the application of the technology needed to meet the 6.0 g/BHP-hr NOx standard and hence there should be no impact on costs.

iv. Total User Costs

In summary, owners of model year 1988 through 1990 HDDVs can be expected to pay an average of approximately $69 more for the emission control on these vehicles than they would have paid without promulgation of the NOx standard. In terms of fuel costs, the increased average lifetime cost per vehicle is expected to be between $0 and $696, tapering off to $0 in later model years. Total lifetime increase is thus $69 to $765 in the short term, and $69 in the long term.

2. 1988 Particulate Standard

a. Cost to HDDE Manufacturers

i. Fixed Cost

The RD&T costs for the non-trap particulate standard were reevaluated, but due to the lack of specific comments, EPA saw no need for major change from those costs presented in the NPRM. Some revisions in the 1988 particulate RD&T costs are caused by changes in the RD&T costs for 1988 NOx control which are allocated equally with particulate control, and general comments indicating the need for more development to deter fuel economy penalties.

The original non-certification RD&T cost was based on four tasks: 1) modifications to the combustion chamber through changes in the piston, 2) changes in injectors and increased injection pressure, 3) changes in the fuel delivery system to refine air/fuel ratio control during transient operation, and 4) changes to the turbocharger to improve air delivery characteristics during transient operation. In the Draft RIA, the cost per task to accomplish this non certification RD&T was estimated at $3,292,000. This was based on 2 design evaluations per task, 4 person-months per design at $50 per hour, and a 10 percent contingency factor, applied to one-half of the 86 engine families. EPA determined that one-half of the families would need the work based on manufacturer comments to the NPRM.

The current estimate for RD&T is based on the same four tasks listed above, as well as on one-half of the cost of applying variable injection timing (VIT). The other half of the cost for developing VIT is included in the RD&T costs for NOx, as is half of the cost of improved turbocharging. Thus, the particulate standard is being allotted the full RD&T cost for three tasks -- piston modification, transient air/fuel ratio control, and improvement in injectors -- as well as half the cost for each of the two tasks of improved turbocharging and VIT. The cost per task in the present analysis is increased from the original estimate by 25 percent in order to account for an additional effort to optimize fuel economy, in response to comments that such an effort will occur. The estimated non-certification RD&T cost for the 1988 particulate standard is therefore $3,292,000 per task X (3 + 2(1/2)) tasks X 1.25 fuel economy effort factor or about $16.5 million.

In the Draft RIA, 1988 HDDE certification was estimated to cost $13 million. Assigning this cost at 50 percent each for NOx and particulate allots $6.5 million of the certification costs to particulate control. This brings the total undiscounted RD&T cost to approximately $23 million.

ii. Variable Cost

Hardware costs, like fixed costs, are calculated much as in the Draft RIA, where they were estimated at $20 per affected engine, based on $5 per modified component. The modified components include: 1) combustion chamber/piston design changes, 2) injector and injection pressure modifications, 3) fuel delivery system changes, and 4) turbocharger improvements. This analysis has changed only to reflect the changes discussed above.

The cost remains at $5 per component for the first three components listed above, while the charge for improved turbocharging is halved to $2.50, with the other $2.50 being allotted to the cost of the 1988 NOx standard. In response to limited comments in this area, an additional $5 is included for improvements in transient control of air/fuel ratio control and turbocharger operation. As was mentioned in the cost analysis for the 1988 NOx standard, electronically controlled variable injection timing will be used to control NOx and particulate. Adding this capability is expected to cost $25 per engine. Half of the cost of variable injection timing, or $12.50 per engine, is also now charged to the particulate standard to accompany such a charge being added to the NOx standard. Summing these costs results in a $35 cost for each engine receiving the modifications; overall, half are expected to receive them. The average cost per HDDE is therefore about $18.

iii. Total Manufacturer Cost

It is expected that the RD&T costs for the 1988 particulate standard will be incurred according to the time table shown in Table 3-19, which is proportional to that presented in the Draft RIA. Costs are shown both undiscounted and discounted to 1988 at 10 percent. Total hardware costs for the three model years following introduction of the standard are based on projected sales for those years as shown in Table 3-11; these costs are estimated using projected sales figures and are given in Table 3-20 in both undiscounted and discounted forms.

Table 3-19

HDDE RD&T Costs for 1988 Particulate

	Undiscounted			Discounted*		
	Non-Certification	Certification	Total	Non-Certification	Certification	Total
1986	$15,000K	$1,000K	$16,000K	$18,150K	$1,210K	$19,360K
1987	$1,500K	$5,500K	$7,000K	$1,650K	$6,050K	$7,700K
TOTAL	$16,500K	$6,500K	$23,000K	$19,800K	$7,260K	$27,060K

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* Discounted at 10 percent to 1988.

Table 3-20

HDDE Hardware Costs for 1988 Particulate

	Undiscounted	Discounted*
1988	$5,915K	$5,915K
1989	$6,178K	$5,616K
1990	$6,422K	$5,307K
TOTALS	$18,515K	$16,838K

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* Discounted to 10 percent to 1988.

Total manufacturer cost is the sum of these total RD&T and hardware costs, and amounts to approximately $41.5 million undiscounted and $43.9 million discounted cost, as shown in Table 3-21.

b. Cost to Users

i. First Cost

The total RD&T cost developed above can be recovered by increasing HDDE prices by $28 for model year 1988-90 engines. When added to the average hardware cost of $18, the total first price increase averages $46 per HDDE. Apportioning this cost only over those vehicles affected by the standard results in a first price increase of about $84 per HDDE.

ii. Operating Cost

As described in the technological feasibility analysis, neither fuel economy nor maintenance is expected to be impacted by the 0.6 g/BHP-hr particulate standard, and hence will not impact user costs.

iii. Total User Cost

The average increase in user cost due to the 1988 particulate standard is the sum of the first price increase and any increase in operating costs. Operating costs are not expected to change, so the average user cost is simply the first cost increase of $46 per model year 1988-90 vehicle equipped with an HDDE.

3. Total Manufacturer and User Costs for 1988 NOx and Particulate Standards

The total HDDE manufacturer cost of compliance with the 1988 standards is developed above for the NOx and particulate standards separately. These costs are shown together in Table 3-22, and total approximately $110 million manufacturer cost discounted to 1988.

The total HDDE user cost per vehicle is also developed above separately for the two standards; the total is shown in Table 3-23 and is $115-$810, depending on the fuel economy penalty. This value will tend towards $115 in later model years as fuel economy improves.

Table 3-21

HDDE Manufacturer Costs for 1988 Particulate

	Undiscounted		Discounted*	
	RD&T	Hardware	RD&T	Hardware
1986	$16,000K	--	$19,360K	--
1987	$7,000K	--	$7,700K	--
1988	--	$5,915K	--	$5,915K
1989	--	$6,178K	--	$5,616K
1990	--	$6,422K	--	$5,307K
	$23,000K	$18,515K	$27,060K	$16,838K
Totals	$41,515K		$43,898K	

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* Discounted to 10 percent to 1988.

Table 3-22

Total HDDE Manufacturer Costs
1988 NOx and Particulate Standards

	Undiscounted		Discounted*	
	RD&T	Hardware**	RD&T	Hardware**
NOx	$30,700K	$33,656K	$35,750K	$30,609K
Particulate	23,000K	18,515K	27,060K	16,838K
Total	53,700K	52,171K	62,810K	47,447K
Grand Total	$105,871K		$110,257K	

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* Discounted at 10 percent to 1988

** Model year 1988-90 HDDVs.

Table 3-23

Total HDDE User Costs
1988 NOx and Particulate Standards

	Fleetwide Vehicle Average	
	First Cost	Fuel Economy
NOx	$ 69	$0-696
Particulate	$ 46	$0
Total	$115	$0-696
Grand Total	$115-810	

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* The $696 fuel economy cost is from a short-term 2 percent fuel economy penalty.

4. 1991 NOx

a. Cost to HDDE Manufacturers

The manufacturer comments which applied to the 6.0 HDDE NOx standard generally applied to the originally proposed 4.0 standard also, with the basic assertion that EPA cost estimates were too low. Specific values for the manufacturer costs of meeting the lower standard were given only by Ford and the Department of Energy (DOE), as follows:

Retail Price Increase Per HDDE, 4.0 NOx Standard

Draft Analysis	$291	from 6.0 to 4.0, HDDE average
	$347	from 6.0 to 4.0, HDDE with new technolog
Ford	$350	from 6.0 to "lowest possible NOx"
	$700	from 10.7 to "lowest possible NOx"
DOE	$643	from 10.7 to 4.0

As in the analysis for the 1988 standard, it is unclear what is included in the cost estimates presented in the comments in regard to such things as RD&T, markup, and percent of engines over which costs are apportioned. The technology changes which are being used to estimate these costs are also not detailed in the comments, although Ford states that all engine models will require air-to-air aftercooling. And finally, DOE presents its value, developed by Argonne National Laboratories (ANL), as the total cost of going from the current NOx level to the final proposed level, rather than as the incremental costs involved with the intermediate level, as EPA does. Ford presents costs for both the total and incremental reductions, but finds the costs to achieve the total reduction without any discounting of fixed costs; DOE also does not discount, making it difficult to directly compare with EPA's estimates.

However, the costs given in the comments are close to those projected by EPA, when apportioned over engines with new technology and using incremental cost from the intermediate standard. The larger values given by Ford and DOE which include the total cost of controlling from 10.7 to 4.0 NOx are approximately twice as high as EPA's incremental estimate, presumably due to the cost of the intermediate standard, which was addressed above.

Therefore, the analysis of HDDE manufacturer costs for the 5.0 NOx standard remains essentially the same as that in the Draft RIA for the 4.0 standard, with changes only in hardware costs in order to reflect comments and to complement changes made for the intermediate standard.

i. Fixed Cost

RD&T costs for the proposed 4.0 g/BHP-hr NOx standard were developed in the Draft RIA. The RD&T costs for a 5.0 g/BHP-hr NOx standard are essentially the same as for the proposed standard at $28,700,000 undiscounted cost, but are delayed one year, along with the standard.

ii. Variable Cost

Hardware costs applicable to the 5.0 NOx standard for HDDEs accrue from additional and improved aftercooling, piston design and turbocharging. The Draft RIA also included costs to cover some portion of the costs for applying electronic control modules (ECMs). However, since manufacturers' comments have indicated that virtually all engines will have such units for reasons other than emission reductions prior to implementation of the standard, costs for electronic control modules are not properly attributable to this standard. Thus, the total hardware cost estimates are reduced from those in the Draft RIA. The other component costs remain the same, however, and are based on comparisons to costs of similar pieces of equipment on existing engines.

Based on manufacturers' comments, engines applying aftercooling for the first time are most likely to use air-to-air aftercooling. As discussed in the Draft RIA, the application of air-to-air aftercooling is estimated to cost $134. It was shown in the Draft RIA that 21 percent of all HDDEs are turbocharged and employ no aftercooling; 10 percent were allocated funds for applying aftercooling in response to the 1988 standard, leaving 11 percent still without aftercooling. Applying the $134 per engine to this 11 percent results in an average of $15 per HDDE. The turbocharged engines which did not receive new or improved aftercooling for the intermediate standard will require it now, at a cost of $73 for converting from air-to-liquid and $91 for upgrading an existing air-to-liquid system. These costs are taken from the Draft RIA and are the same as used above for the 6.0 standard. For the 6.0 NOx standard it was projected that 5 percent of all HDDEs would convert from air-to-liquid to air-to-air aftercooling and 16 percent would upgrade current air-to-liquid systems. For the 1991 standard it is projected that another 5 percent will convert to air-to-air and 15 percent will upgrade air-to-liquid systems. On a weighted basis, the average cost of improved aftercooling is $17 per HDDE.

The component cost and amount of application of piston redesign remains as in the Draft RIA, at $5 per engine at a 25 percent application rate. EPA's best estimate based on manufacturer comments results in $1.25 per HDDE.

Earlier in this analysis, it was projected that 50 percent of the HDDEs would need turbocharger improvements to meet the 1988 NOx and particulate standards. Improved turbocharging is now expected to be employed on the remaining half of the engines to meet the 1991 NOx standard at a cost of $5 per engine, as allotted for the intermediate standard. This results in $2.50 per HDDE.

EGR is eliminated as an expenditure to meet the 1991 NOx standard, in a response to indications from the manufacturers that they will not employ EGR on their engines. Electronic control module hardware costs are also eliminated, as discussed above, although RD&T costs were allocated for software design.

Total hardware costs are then the total of the above costs for aftercooling, piston design, and improved turbocharging. This amounts to $36 per engine average hardware cost, or $113 per HDDE receiving the new hardware.

iii. Total Manufacturer Cost

To calculate total manufacturer cost, RD&T and hardware costs must be discounted to the year of the standard, 1991. The distribution of RD&T costs which was given in the Draft RIA and is used again here is shown in Table 3-24. Hardware costs expended according to sales projections and discounted to the year of the standard are shown in Table 3-25. The total manufacturer cost arises from the sum of these costs, and is developed in undiscounted and discounted forms in Table 3-26. Total manufacturer cost of compliance with the 1991 HDDE NOx standard is shown to be about $71 million undiscounted and $73 million discounted to 1991.

b. Cost to Users

i. First Cost

Incremental increases in first cost due to the 5.0 HDDE NOx standard are determined in the same manner as described previously, except fixed costs are recovered over 1991 through 1993 model year HDDEs. The average increase in first cost of HDDEs would consist of the sum of the discounted RD&T costs amortized over sales for model year 1991 through 1993 plus the hardware cost developed above. These costs are approximately $32 for RD&T and $36 for hardware for a total of $68 average HDDE first price increase. These costs can also be expressed per HDDE requiring new technology rather than as average per engine cost by adding RD&T cost apportioned only over these engines to the cost of the hardware required. These costs are approximately $44 for RD&T and $113 for hardware, for a total for $157 for an engine receiving all of the new technology.

Table 3-24

HDDE RD&T Costs for 1991 NOx

	Undiscounted			Discounted*		
	Non-Cert. Costs	Cert. Costs	Total	Non-Cert. Costs	Cert. Costs	Total
1988	$7,000K	-	$7,000K	$9,317K	-	$9,317K
1989	14,000K	1,000K	15,000K	16,940K	1,210K	18,150K
1990	1,200K	5,500K	6,700K	1,320K	6,050K	7,370K
Totals	$22,200K	$6,500K	$28,700K	$27,577K	$7,260K	$34,837K

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* Discounted at 10 percent to 1991.

Table 3-25

HDDE Hardware Costs for 1991 NOx

	Sales	Undiscounted	Discounted**
1991		$13,673K	$13,673K
1992		14,209K	12,917K
1993		14,423K	11,920K
TOTAL		42,305K	38,510K

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* Sales taken from Table 3-11.

** Discounted at 10 percent to 1991.

Table 3-26

HDDE Manufacturer Costs for 1991 NOx

	Undiscounted		Discounted*	
	RD&T	Hardware	RD&T	Hardware
1988	$7,000K	--	$9,317K	--
1989	15,000K	--	$18,150K	--
1990	6,700K	--	7,370K	--
1991	--	$13,673K	--	$13,673K
1992	--	14,209K	--	12,917K
1993	--	14,423K	--	11,920K
	$28,700K	$42,305K	$34,837K	$38,510K
TOTAL	$71,005K		$73,347K	

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* Discounted at 10 percent to 1991.

The cumulative increase in first cost over current engines to achieve compliance with the 1991 standard would be the sum of the costs for 1988 and 1991. The total increase in first cost is thus $69 for 1988 hardware plus $68 for 1991 or $137.

ii. Fuel Economy

In Chapter 2, Technological Feasibility, it was estimated that fuel economy penalties associated with the 1991 standard would be in the range of 0 to 1 percent in the short term, and this penalty should tend to decrease to one-half percent with time as vehicle and engine improvements are made. The 0 to 2 percent penalty associated with the 1988 standard should have disappeared by 1991.

Fleetwide fuel economy costs are calculated in the same manner as for the 1988 standard, amounting to an average per vehicle lifetime increase of $348 per 1 percent increase in fuel consumption. With a 0 to 1 percent change in fuel economy expected for the 5.0 standard, the short term fuel cost increase is thus $0 to $348, tapering off to $0 to $174 over the long term.

Several commenters--Mack, American Trucking Association, and Department of Energy--indicated the fuel cost increases would be much greater than this. All estimates, however, were based on a variety of different assumptions regarding vehicle lifetimes and amount of fuel currently used, as well as on higher fuel economy penalties. The fuel economy penalty issue is most important, and is addressed in Chapter 2, Technological Feasibility; the other issues are methodology differences of VMT and fuel price estimates, and are discussed above in regard to the 1988 HDDE NOx standard.

iii. Maintenance

Maintenance is not expected to be affected by this standard, and hence should not impact on cost.

iv. Total User Cost

In summary, owners of model year 1991 and later vehicles which are equipped with HDDEs can be expected to pay an average of approximately $68 incrementally over model year 1988 through 1990 vehicle prices or $137 total more than they would have paid without the introduction of the two HDDE NOx standards. In terms of fuel costs, the increased average lifetime cost per vehicle is expected to be between $0 and $348, tapering off in later model years to $0 to $174. Incremental lifetime increase is thus $68 to $416 in the short term, and $68 to $242 in the long term. Total lifetime increase for model year 1991 and later HDDEs due to the NOx standards is $137 to $485 in the short term, and $137 to $311 in the long term. These costs are summarized in Table 3-27.

5. 1991 Diesel Particulate Standards (0.25 g/BHP-hr for HDDEs with 0.10 g/BHP-hr for Urban Buses)

In this section, the costs of the 1991 diesel particulate standards for HDDEs are examined. As described in the Technical Feasibility Chapter (Chapter 2), achieving these standards will require the use of trap-oxidizer technology on 100 percent of the urban buses and about 60-70 percent of the remaining HDDEs. Since the same basic type of trap-oxidizer system will be used on both HDDEs and urban buses, in the subsequent analysis of comments and cost derivations, the primary discussion in each section centers on HDDEs in general, and is then followed by a discussion of any special considerations of urban buses, as necessary.

a. Cost to Manufacturers

i. Fixed Cost

In the draft analysis, EPA separated research and development costs into three categories: 1) general system development; 2) specific engine family design; 3) electronic control development. The seven largest HDDE manufacturers were each allotted about $2.8 million to develop general trap systems. Smaller manufacturers were expected to rely on guidance from trap-oxidizer manufacturers for general designs. Engine family specific designs were assumed to be required by about 70 percent of the engine families with averaging, at a cost of about $230,000 per engine family. The development of electronic controls was estimated at about $115,000 for each engine family.

Three comments were received regarding EPA's research and development cost estimates. In the first comment, GM stated that EPA had clearly underestimated the cost of basic trap development, claiming that it had already expended $40 million by the end of 1984. In presenting it's $40 million expenditure, GM failed to distinguish what portion of this amount is attributable to LDD trap development and which is attributable to HDDE trap development. Without this information, it is impossible to know how much GM has indeed spent on trap systems for HDDEs. The company's claim can be placed in perspective, however, by the fact that LDD regulations requiring trap technology were promulgated for the 1985 model year in early 1980.[4] (These requirements were subsequently delayed in early 1984 until the 1987 model year.)[5] By contrast, HDDE trap requirements for the 1991 model year are just now being promulgated in this rulemaking.

Table 3-27

Heavy Duty Diesel Engines
Discounted* User Cost per Engine for 1988 and 1991 NOx

	1988 Standard	1991 Standard	Total
SHORT TERM:			
RD&T	$37	$32	$69
Hardware	$32	$36	$68
Fuel	$0 to 696	$0 to 348	$0 to 348
TOTAL	$69 to 765	$68 to 416	$137 to 485
LONG TERM:			
RD&T	$37	$32	$69
Hardware	$32	$36	$68
Fuel	$ 0	$0 to $174	$0 to 174
TOTAL	$69	$68 to 242	$137 to 311

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* At 10 percent per year to the year that standard becomes effective.

Additionally, most trap-related technical information submitted to EPA by GM has concerned light-duty traps. It seems reasonable to expect, therefore, that only a small portion of GM's total trap development expenditures should be attributed to the HDDE trap standards. The Agency would also like to point out that due to the problematic nature of estimating development expenditures for each manufacturer, EPA's projection should be reviewed in terms of an overall average per manufacturer, with some spending more and others less. Because of its size, it is not unreasonable to expect that GM should fall into the former category. Hence, GM's comment provides no basis for revising EPA's original estimate of general development costs.

The second comment, which was confidential, identified another company's expenditures for HDDE trap development from 1979 through 1984. In this case, the reported values were well within EPA's estimate for each manufacturer. Therefore, the original estimate for general system development appears to be appropriate based on this comment.

The third comment came from International Harvester which claimed that its mechanical durability testing would require 11 LHDDVs and 13 MHDDVs with each vehicle successfully traveling 100,000 miles and 150,000 miles, respectively. While not agreeing with the need for such a large test fleet, EPA calculates the cost of such a program at about $2.3 million. This amount is less than half of the development cost for IH as derived in the draft analysis. Therefore, the comment provides no basis for changing EPA's original research and development estimates.

Another area of comment concerning development costs was that of vehicle modifications. The draft analysis did not contain a cost for development and tooling expenditures which might be needed to modify the vehicle assembly to integrate the trap-oxidizer into the overall design. International Harvester expressed the strongest concerns regarding the potential magnitude of vehicle modifications. In an apparent reference to tractor-trailer combinations, IH stated that if two traps are necessary and their size requires that they be mounted behind the cab, then the location of such things as the sleeper unit, fuel tank, air tanks, fuel and oil filters, aerodynamic side shields, etc. may be affected. This would in turn adversely affect hundreds of body builders. General Motors stated that in its evaluation of possible vehicle design changes, there appears to be adequate room within the vehicle frame on a MHDDV to mount a trap and muffler, although a few vehicle components may need to be relocated on some versions. For its HHDVs, GM claimed that if mounted behind the cab, traps may restrict the vehicles turning radius which, in turn, may reduce tractor-trailer offerings. General Motors also alledged that "essentially" no space was available for a trap in it's urban bus, and that significant redesign of this vehicle would be required. The company claimed that potential changes may include relocating air conditioner and heater components, eliminating seating for up to five passengers, or installing new suspension systems and bulkheads. Cummins generally commented on the need for vehicle modifications without identifying specific changes required.

EPA agrees with the commenters to the extent that vehicle modifications may be required for certain trucks in order to accommodate trap oxidizers. The extent of any required vehicle modifications will obviously be dictated by the type of trap system ultimately chosen by manufacturers, and upon its specific configuration. Since neither the final trap type nor specific configurations have yet been identified, the potential costs associated with required vehicle redesign can not be quantified to any degree. However, it is possible to discuss in general terms the types of trucks that are most likely to be affected and how the negative effects of any redesign might be minimized.

As stated by GM, the greatest potential for vehicle modifications is associated with HHDDVs and urban buses. Regarding HHDDVs, and all other diesel trucks for that matter, it should be remembered that diesel particulate emissions averaging will result in a significant number of trucks not needing traps. To the extent that a manufacturer can anticipate problem installations, such vehicles/engines might be excluded from having traps. Beyond this, it is reasonable to expect that many HHDDVs and urban buses will normally undergo some design changes by the 1991 effective date of the standards, especially in light of the emphasis being placed on improved aerodynamics by HDDV manufacturers. For such vehicles, the incremental cost of incorporating traps in the design would be minimal. Finally, there are many vehicles for which creative packaging of the trap system will avoid costly redesigns. For example, Southwest Research Institute is currently testing a GM coach engine with a trap configured to replace the engine's exhaust manifold.[6] Such a design would require no redesign of the urban bus.

Overall, then, while modifications will likely be needed on some vehicles, the extend of these changes will in large part be dictated by the engine manufacturers choice of trap system, and the foresight with which it is configured or packaged to meet the requirements of the vehicle manufacturer or body builder. Therefore, EPA believes that the number of significant design changes can be minimized, and when averaged over the fleet their impact will be small. Because of this, no fixed cost for vehicle modifications will be included in the cost of the regulations.

In addition to the expense of research and development, the draft analysis included the fixed cost of emission certification testing. No comments were received on this cost component, so it is being retained here without change.

In summary, none of the comments supported any changes to the fixed costs of the draft analysis. They are therefore being retained unchanged. Nonetheless, it is interesting to note that even if the comments had provided a basis for revising the fixed cost estimates, any corresponding change in the total cost of the regulations would be very small. As will become evident later in this analysis, fixed costs are only about eight percent of the total cost.

As shown in Table 3-28, the total fixed cost of the 1991 particulate standards is $49.5 million. The distribution of the expenditures over time is the same as originally estimated in the draft analysis, except each allocation has been delayed one year to account for the revised effective date of the standards from 1990 to 1991.

ii. Variable Costs

The draft analysis explored the potential use of two significantly different types of trap oxidizers for HDDEs: a non-catalyzed, ceramic monolith system; and a catalyzed wire-mesh system. As fully described in the Diesel Particulate Study (DPS),[2] which accompanied the draft analysis, both systems function similarly in that particulate matter is filtered from the exhaust and then periodically burned in the trap to prevent excessive exhaust backpressures which would degrade engine performance and fuel economy. This latter step is termed "regeneration" and is significantly different in the two trap types, depending on the presence or absence of a catalyst. The ceramic monolith design assumed in the draft analysis used a fuel burner to heat the trapped material to its ignition point. During this process, the engine exhaust flow is temporarily routed around the trap, while the burner and trap are supplied with a controlled air supply to ensure adequate oxidation of the trapped material without excessive heating. The regeneration system with a catalyzed wire-mesh trap can be less complex, since the requisite temperature increase of the trap is significantly less. The catalyst trap evaluated in the draft analysis was assumed to achieve the required moderate heat rise by delayed in-cylinder fuel injection; thereby, eliminating the need for a fuel burner and bypass system.

In assessing the variable or hardware cost of the two systems, the draft analysis found that the wire-mesh design with its catalyst coating was quite expensive. Hence, the

Table 3-28

Total Fixed Costs of the
1991 HDDE Particulate Standards

Year	Development	Certification	Total
1987	$8.0M		$8.0M
1988	20.0M		20.0M
1989	13.0M	$1.0M	14.0M
1990	2.0M	5.5M	7.5M
Total	$43.0M	$6.5M	$49.5M

ceramic monolith trap with a fuel burner regeneration system was used to estimate the cost of the proposed HDDE particulate standards. A summary of the hardware costs that were used in the proposal are shown in Table 3-29.

Comments on the cost of trap-oxidizer systems were received from six manufacturers, one of which was confidential. Cost figures were also provided by the Department of Transportation and the Department of Energy. Unfortunately, each of the government estimates were supplied as a composite total of the trap-oxidizer standards in conjunction with either the 1988 non-trap standard or the 1991 HDDE NOx standard and, therefore, could not be analyzed in detail. Hence, these latter two comments are not discussed further. The non-confidential industry estimates are displayed in Table 3-30.

The manufacturers estimates in Table 3-30 were generally reported as the cost of a total system. Little, if any information was provided as to the derivation or basis of the estimates. For example, the manufacturers usually provided no breakdown of the total system into its various cost components. Also, the estimates were variously described as "cost to the consumer" or "consumer effect." Therefore, it is unclear if some of these costs include fixed or operating costs, or whether they inappropriately reflect the full retail cost of a trap system, rather than the incremental cost for a new vehicle. Even if only a 1 percent penalty were included in some of these estimates, this could add about $350 to the total cost for an average HDDE when discounted to the year of vehicle purchase.

Cummins was the only manufacturer shown in Table 3-30 that provided a breakdown of its system cost by hardware component. As reported by the company, the component costs are as follows:

1.	Trap Substrate Material	$720-$1,080
2.	Trap Casing and Ceramic Mounting	$250
3.	Diesel Burner for Regeneration	$400
4.	Electric Air Blower for Burner	$175
5.	Miscellaneous Control Costs	$650
	Total	$2,195-$2,555

Cummins describes the trap substrate, i.e., ceramic monolith, as being 60-90 liters for a "possible dual trap option" at $12 per liter. Additionally, the costs are described as component costs from suppliers, without an allowance for assembly, machining of other ancillary parts, or fixed manufacturing costs.

Table 3-29

Trap-Oxidizer Variable Cost From the Draft RIA

Cost Category	LHDDE	MHDDE	HHDDE
Ceramic Monolith and Housing	$207	$343	$402
Burner	7	14	14
Fuel Delivery System	9	18	18
Fuel Ignition System	26	21	21
Auxiliary Air System	30	30	30
Exhaust Diversion System	45	69	105
Sensors	12	24	24
ECU	37	37	37
Total Hardware	$363	$556	$652

Table 3-30

Manufacturers' Trap-Oxidizer Cost Estimates

Source	Cost	Description
IH	$1285-2070	MHDDE, single trap
	4710	HHDDE, single trap
	7210	HHDDE, dual trap if required
Ford	2200	No comment
Cummins	2810-3270	HHDDE, possible dual trap option
GM	575-900	LHDDE
	2300	MHDDE, single trap
	4000	HHDDE, dual trap
Saab	2500+	No comment

The confidential comment also provided some breakdown of cost by component. Due to the confidentiality of the comment, however, all that can be said is that in contrast to Cummins estimate, the reported trap cost, (i.e., substrate and housing) is substantially less expensive, while the air supply and burner are somewhat more expensive.

The lack of detail in the cost comments, including Cummins', makes a rigorous analysis of the estimates impossible. The only clear conclusion that can be reached is that the cost of a trap-oxidizer system as reflected by the manufacturers comments is substantially higher than EPA's estimates from the Draft Analysis (Table 3-29). In order to address this disparity, EPA's only recourse has been to completely reevaluate its estimates, using the comments where possible, to better define the variable costs of the regulations. In preparing this reevaluation, EPA has also made use of an independent contractor to prepare component cost estimates.

Overview of the Analysis

In reevaluating the variable cost of trap-oxidizers for HDDEs, EPA will examine the component costs of three separate systems. The first system uses a ceramic monolith trap in conjunction with a fuel burner and exhaust bypass for regeneration. This is very similar to the trap-oxidizer unit used in the draft analysis to estimate the costs of the proposal. The second system is the same as the first, in that a ceramic monolith is used to filter the exhaust, but differs with regard to the type of heat source used to initiate regeneration. In this system, electric heating elements are included in the trap housing and are energized with the vehicle's electrical system. An exhaust bypass is also required with this system. Electrically regenerating the trap can be advantageous since it eliminates the bulk and safety considerations associated with the fuel burner approach. The third system is radically different from the others in both trap design and method of regeneration. The filter medium in this trap design is composed of ceramic fibers which are wound into a type of fabric. Regenerating the ceramic trap is accomplished through the use of a metallic catalyst compound that is injected into the exhaust at the time regeneration is desired. Since the catalyst substantially reduces the ignition temperature of the trap particulate material, no exhaust bypass system is required. This system is attractive primarily because its simplicity could result in reduced costs compared to the other two systems. Each of these systems will be further described below.

Most research and testing to date have focused on the ceramic monolith trap. Of the two regeneration methods described above, the fuel burner concept has been successfully used in vehicle tests and its hardware components are well understood. The electrical regeneration system, on the other hand, is much less well defined at the present time. The ceramic fiber trap and catalytic regeneration system is the most recent entrant in the trap-oxidizer field. The trap concept is proprietary to Mercedes-Benz AG and relatively little is known about it compared to the ceramic monolith trap. Due to the present state of knowledge, the cost of a ceramic monolith/fuel burner system can be estimated with the greatest degree of certainty. Therefore, as in the draft analysis, this system will be used to derive the variable costs associated with the 1991 particulate standards. Also, considering its state of development, this trap-oxidizer design could be the first commercially available system.

The variable costs of the ceramic monolith/electric system and ceramic fiber/catalyst system are still of interest, however, since their potential advantages may result in either or both of these supplanting the ceramic monolith/fuel burner design. Therefore, these systems are examined here to provide a measure of sensitivity to the overall cost estimates.

The variable cost of each trap-oxidizer system is found by determining the retail price equivalent (RPE) of each component part. With few exceptions, the costs were based on work performed by Mueller Associates under contract to EPA.[7, 8] The contractor's estimates were based on the manufacturer's cost of each component. To obtain the required RPE of the various components, EPA adjusted the contractor's estimates to reflect the added costs associated with a manufacturer's overhead and profit, in addition to dealer costs. The mark-up factor used to derive the RPE of each component was 1.29 (i.e., a 29 percent increase). This factor has been used in past rulemaking actions and is derived in Reference 9.

The costs not taken directly from the contractor were estimated by EPA and will be specifically identified were applicable in the discussion. The Agency's estimates are based on previous work by Lindgren,[10] information supplied by Mueller Associates,[7,8] the DPS, and on engineering evaluations of similar automotive components.

Now that the general methodology has been described, estimates of the various component costs can be presented. This will be done first for the two trap designs and then for the three regeneration systems. After the component parts have been estimated, the resulting total cost of each system will be presented.

Ceramic Monolith Trap Costs -- The cost of any specific trap design is dependent on the volumetric requirements of the filtering medium. One of the most important considerations in sizing a trap is to make it large enough to avoid undue exhaust backpressures, which would degrade engine performance and adversely affect fuel economy. In general, the requisite trap volume for a given engine is dependent on the volumetric exhaust flow during normal operation. The HDDE trap sizes assumed in the proposal were derived in the DPS. The analysis was based on successful testing of a 5.0 liter trap on a Mercedes-Benz 300D by Southwest Research Institute for EPA.[11] Since volumetric exhaust flow from an engine is roughly a function of the amount of fuel consumed (i.e., inverse of fuel economy), HDDE trap sizes were estimated by increasing the LDDV trap size (i.e., 5.0 liter) by the ratio of the vehicle's MPG (26 MPG) and the projected average MPG's of each HDDE size category. The resulting HDDE trap volumes, which were used to estimate the cost of the proposal, varied from 8.3 to 18.4 liters depending on HDDE size.

No comments were received on this method of sizing HDDE traps. The Agency's estimated trap volumes, however, contrast sharply with cost comment from Cummins indicating the use of a 60-90 liter trap in its calculations. Unfortunately, Cummins provided no information describing how it arrived at this size. In addition, trap test data supplied by GM (described further below) are based upon trap volumes somewhat greater than estimated by EPA. This disparity has caused EPA to reevaluate its sizing methodology.

The major difficulty in attempting to estimate exhaust flow changes from one vehicle or engine type to another is in choosing a sizing parameter that accurately reflects the many variables which ultimately determine the actual exhaust volume. Such key variables include air/fuel ratio, vehicle and engine speed, engine efficiencies, and how the engine is loaded in normal operation, i.e., what percentage of the engine's rated horsepower is typically used. As vehicles become more disparate in size and function, the accuracy of any single parameter for estimating exhaust volumes will diminish due to the multitude of variable interactions. This notwithstanding, EPA continues to believe that fuel consumption is a reasonable surrogate for approximating exhaust flows. It inherently accounts for many of the changes in vehicle operating regimes and engine operating parameters among vehicle types.

While fuel consumption appears to be a useful method for estimating exhaust flows, EPA also recognizes that the wide disparity in operating regimes of LDDV engines and some HDDEs, especially the heaviest trucks, could result in this approach being somewhat inaccurate for such HDDEs. Therefore, at least for some applications, engine horsepower also may be a useful sizing parameter.

To explore this method, a review of EPA trap-oxidizer test programs and the information submitted in response to the proposal was conducted. This review showed that several different combinations of trap volume and engine horsepower have been tested. Two EPA test programs are useful in this comparison. First, the previously referenced Mercedes-Benz 300D test was conducted with a 5.0 liter ceramic monolith trap. The rated power of the engine used in this vehicle model is 118 HP.[12] Second, EPA has also tested a GM bus engine with a 20 liter trap.[13] This MHDDE has a rated power of 190 HP.[12] While the results were quite variable, overall essentially no fuel economy penalty was observed with this trap volume/engine size combination. The trap volume (liters) to horsepower ratios from these tests are about 0.04 for the "EPA-LDDV" and about 0.10 for the "EPA-MHDDE."

The comments contained test data for two additional engines. The first engine has a rating of 205 HP,[12] and was tested by GM with trap sizes ranging from 20-25 liters. The information submitted by GM for some of these tests shows what appears to be quite reasonable pressure drops across the trap during actual over-the-road vehicle testing. Hence, this trap volume/engine combination may represent an acceptable trap volume to horsepower ratio from the standpoint of minimizing any potential fuel economy penalty. The average trap volume to horsepower ratio for the "GM-MHDDE" is 0.11. The comments also contain confidential test results on a LHDDE vehicle. Due to the confidential nature of the comment, however, all that can be stated is that the trap volume to horsepower ratio for this test was somewhat less than the EPA-MHDDE factor. The Cummins comment regarding trap volumes is not used here since the basis of the estimate was not reported.

Table 3-31 presents a summary of the average trap volumes that result from applying the various factors discussed above (i.e., both MPG and horsepower based) to the average fuel economy and horsepower ratings for the various HDDEs. Note that the MPG values shown in the table have been updated from those in the DPS, as discussed in the section on the 1991 HDDE NOx standard. This has resulted in revised HDDE trap volumes using the fuel consumption sizing method.

From the table, it is readily apparent that the various approaches result in a wide range of estimates. The lowest values are consistently estimated by the EPA-LDDV horsepower approach. This is not surprising given that a trap would likely be sized or optimized for the most typical type of operation. The power requirements of a LDDV under normal operation is usually less than that for a diesel truck when expressed as a percentage of the engine's rated horsepower. For LHDDEs the difference may be rather small, but the

Table 3-31

Summary of HDDE Trap Volume Estimates

			Fuel Economy and Horsepower Based Volumes			
HDDE Category	Average MPG	Average Estimated HP	EPA Fuel Economy Factor	EPA LDDV HP Factor	EPA MHDDE HP Factor	GM MHDDE HP Factor
LHDDE	15.1	130	8.6L	5.2L	13.0L	14.4L
MHDDE	8.0	200	13.3L	7.4L	18.5L	20.4L
HHDDE	5.9	350	22.0L	14.0L	35.0L	38.5L

disparity becomes progressively greater as the HDDE size is increased. As a result, the EPA-LDDV horsepower factor would progressively underestimate HDDE trap volume requires as the HDDE size of the vehicle increased.

At this point, some judgment must be used in conjunction with the remaining fuel economy based and horsepower based values shown in Table 3-31 to identify reasonable HDDE trap volumes. An extremely important consideration in this decision is the tradeoff between trap volume and effects on fuel economy. In this respect, it can generally be concluded that the cost of a somewhat larger trap is much less than the cost of adversely affecting fuel economy by using a trap that is too small. Hence, it is EPA's intent to be conservative, (i.e., to err toward larger volumes) in estimating trap volume requirements.

Most LHDDEs are loaded and driven much like LDDVs. This argues strongly in favor of using the fuel economy based estimate, since this method should be quite accurate in this case. To be conservative, however, the trap size for this category will be estimated by averaging the EPA LDDV fuel economy based volume with the various horsepower based volumes. The result is an estimated volume of 11 liters for LHDDEs. Considering that the operating regimes of MHDDEs and HHDDEs become increasingly dissimilar to LDDVs and LHDDEs as truck size grows, and that the EPA and GM horsepower factors are based on tests that should not result in undue fuel economy penalties, the GM-MHDDE horsepower factor will be used to estimate trap volumes for these vehicles. The resulting estimates are 21 liters for MHDDE and 39 liters for HHDDEs.

Another important detail which must be dealt with before the trap costs can be estimated is the number of traps that may be required by the variously sized HDDEs. The DPS assumed the number of traps for each HDDE size as follows: one for LHDDEs, two for MHDDEs, and two for HHDDEs. No comments were received regarding the number of traps for LHDDEs. The comments from IH and GM indicate one trap will be sufficient for MHDDEs (Table 3-30). GM provided an illustration of this concept that showed two ceramic monoliths arranged in series to provide the necessary volume.

The comments for HHDDEs are indecisive with regard to the number of traps per vehicle (Table 3-30). The Cummins and IH comments suggest single traps are possible. Also the Cummins comment regarding the possible dual trap requirement would seem to be invalidated given that the trap volume requirements estimated above are significantly less than assumed in its description. GM's comment was provided in the context of its 12.1 liter, 435 HP engine. This engine is significantly larger than most of the engines in this HDDE size category. It is possible such a large engine might require two traps. However, even in this situation, placing trap monoliths in series to attain the required volume is possible, although some increase in backpressure would result. Based on the comments and the requisite trap volumes, EPA believes that for most if not all HDDEs, a single trap is sufficient if not preferable for system simplicity.

The ceramic monolith trap has several components. These components include the monolith itself, a ceramic mat and a trap housing. Each component and its associated cost is discussed below.

The ceramic monolith material is constructed as a matrix of alternatively opened and closed cells. Particulate material is collected as the exhaust flows through the porous wall of one channel into the next. The monoliths used for HDDEs are assumed to be approximately 12 inches in diameter, although smaller sizes can also be made. The cost is estimated at about $6 per liter, based on information from Corning, one of the largest ceramic monolith manufacturers.[8] This can be contrasted with the $12 per liter cited by Cummins in its comment, which was unreferenced. Using the former value, the estimated price of the ceramic monolith material for the various HDDEs is: $66 for LHDDEs, $126 for MHDDEs, and $234 for HHDDEs.

The ceramic mat holds the monolith securely within the housing. It also functions as a shock absorber and provides thermal insulation. This item is estimated at $3, $6, and $12 for LHDDEs, MHDDEs, and HHDDEs, respectively.[8]

The trap housing encloses the ceramic monolith and ceramic mat. It includes baffles, flanges, and pipe connectors (used to connect the trap to the exhaust system and fuel burner or bypass valve), in addition to fittings for mounting sensors. The estimated cost is $32 for LHDDEs, $40 for MHDDEs, and $46 for HHDDEs.[8]

Table 3-32 presents the total estimated cost of a ceramic monolith trap for each of the HDDE size categories.

Ceramic Fiber Trap Costs -- Other than the basic construction of this trap design, little specific information is available. In general, perforated stainless steel cylinders are wound with silica fibers until the desired filter "fabric" has been created. Several such tubes are then arranged in parallel inside the stainless steel housing so that the exhaust must pass through the fabric and into the stainless cylinder before exiting the trap. To estimate the cost of this trap design, the volumetric requirements that were developed for the

Table 3-32

Estimated HDDE Trap Costs

Trap Design	LHDDE	MHDDE	HHDDE
Ceramic Monolith	$101	$172	$292
Ceramic Fiber	73	106	140

ceramic monolith are assumed to apply. The cost for the entire ceramic trap is estimated at $73 for LHDDE, $106 for MHDDE, and $140 for HHDDE.[7] These costs are also shown in Table 3-32.

Fuel Burner Regeneration System Costs -- A typical system of this type has several primary components: a burner can, a fuel delivery system, an ignition system, an auxiliary air supply system, an exhaust diversion system, and an electronic control system. An additional component required by the trap-oxidizer which is actually neither part of the trap nor regeneration system is the exhaust pipe. The cost of this component and the others are discussed below.

The burner can is located just upstream of the trap. The can is designed to contain the flame and distribute the heat output (e.g., about 100,000 Btu/hour) evenly across the face of the trap. Additionally, the unit provides a location for mounting the fuel injection nozzle, ignition plug and flame sensor, and auxiliary air injection nozzle. Due to the operating environment and required long life, the burner can is largely made of high grade stainless steel. The basic cost of this component is relatively insensitive to variations in heat output requirements. Therefore, the estimated cost of $21 is used for all HDDEs.[7]

The fuel delivery system is composed of a fuel injector, control solenoid, fuel line, and fuel line connectors. This system is used in conjunction with the vehicle's existing fuel injection system. The use of an electric solenoid provides precise control of the regeneration rate, and provides effective overtemperature protection. The fuel injector and solenoid is estimated at $12 for all HDDEs.[7] The fuel line and connectors are estimated by EPA to cost about $2 per vehicle.

The ignition system provides spark ignition and flame control. The components include an electrode, an inverter, and a step-up voltage transformer for generating a high-voltage discharge. Also, the system includes a flame sensor and sensor relay as a safety consideration for cutting off fuel to the burner if combustion fails. Mueller Associates estimated the cost of a continuous spark system.[8] The Agency finds that a somewhat smaller system providing a periodic spark, when used with the flame sensor, is fully satisfactory. As a result, EPA estimates the system to be approximately 20 percent less than the contractor's estimate, or $35 for all HDDEs.

The auxiliary air system supplies a controlled amount of air to the burner and trap during regeneration. Its components include an air pump, a control valve operated by an electric solenoid, and an air delivery line with connectors. The air pump is driven by the vehicle engine and is a larger, more durable version of those already used on light trucks and heavy-duty vehicles. It is equipped with a check valve to prevent exhaust backflow into the air pump. Since air is only required during regeneration, the air pump is assumed to be equipped with an electric clutch so that it can be disengaged from the engine in order to save fuel. The Agency estimates the cost of the air pump and electric clutch to be about $45 and the associated air delivery tubing with connectors at about $5 for all HDDEs. The control valve and electric solenoid for this system are estimated at $14 per vehicle.[7]

The exhaust diversion system consists primarily of a bypass valve and a solenoid controlled actuator that temporarily reroutes the exhaust around the trap during regeneration. The bypass valve is a butterfly type constructed of stainless steel, located just upstream of the combustor. In estimating the price of this unit, the cost of a stainless steel exhaust pipe has been included. This pipe will replace the standard steel exhaust pipe that normally extends from the engine manifold, or turbocharger, to the muffler. In the DPS, the cost of the stainless steel pipe included a credit for the standard steel pipe which it replaced. In this analysis, the standard steel pipe is assumed to be roughly equivalent to that required to bypass the trap. Therefore, the full cost of a stainless steel exhaust pipe is included in the cost of the bypass valve. This component is estimated at $49 for LHDDEs, $52 for MHDDEs, and $58 for HHDDEs.[8] The electric solenoid/actuator is estimated to cost $15 for all HDDEs.[8]

To initiate and control regeneration, several different sensors, an electronic control unit, and wiring harness will be required. A backpressure sensor will detect the need for regeneration and is estimated to cost $17 per HDDE.[7] A trap temperature sensor estimated to cost $5, and will be used to protect the trap from excessive heat.[8] A sensor will also be used to ensure the engine has reached the proper temperature before regeneration is initiated. This sensor was estimated to cost about $1 in the DPS.

Regarding the electronic control unit, manufacturers are expected to equip essentially all HDDEs with such units by the 1990s, irrespective of emission standards. For this reason, the electronic capability required for trap regeneration will be added to the existing unit. This incremental cost is estimated at about $34 per HDDE.[8] The wiring harness to connect the sensors to the electronic control unit is estimated to cost $14 for LHDDEs and $18 for MHDDEs and HDDEs.[8]

Based on the above discussion, the total cost of the fuel burner regeneration system is estimated to be $269 for LHDDEs, $276 for MHDDES, and $282 for HHDDEs. The various component costs are summarized in Table 3-33.

Electric Regeneration System Costs -- This type of regeneration system uses many of the same component parts that are required by the fuel burner regeneration system. These include an auxiliary air supply system, exhaust diversion system, and electronic control system. The exception is, of course, the replacement of the fuel burner with an electrical heating system. The costs for each of these systems will be estimated below, with the discussion focusing on the components that are different from those described for the fuel burner system.

The auxiliary air supply uses an air pump and electric clutch, as required by the fuel burner system, except that the pump is somewhat smaller in size because air is provided only to the trap. The Agency estimates this to cost about $40 per HDDE. The control valve and solenoid is retained at $14, as is the air delivery line and connectors at $2 per vehicle.

The exhaust diversion and electronic control systems remain unchanged from those used in conjunction with the fuel burner. The exhaust diversion system was estimated at $64 for LHDDEs, $67 for MHDDEs, and $73 for HHDDEs. The electronic control system was estimated at $71 for LHDDEs and $75 for the other HDDE size categories.

The cost of the electrical heating system is difficult to estimate because the specific requirements of the system are yet to be well defined. The Agency envisions a rather modest system that depends on the vehicle's existing electrical system. In this concept, the additional electrical power required for regeneration is provided by using the existing batteries in conjunction with a larger alternator. The electric current from the battery is conducted by cable to the electric resistance heating elements which are mounted in the trap housing. The cable is equipped with a fusable link to protect the batteries and charging equipment in the event of a short circuit. The power supply to the electric heating element is controlled by the electronic control unit through the use of an electromechanical relay. Based on alternator costs supplied by Mueller Associates, EPA estimates the incremental cost of the requisite alternator to be about $47 for LHDDEs, $56 for MHDDEs, and $67 for HHDDEs. The cable with a fusable link is estimated to cost $7, while the relay is estimated at $10 per vehicle. The electrical heating elements with mounting hardware are estimated to cost $14 for LHDDEs and $18 for the other HDDE size categories.

Table 3-33

HDDE Costs for Trap Regeneration System

Cost Category	Fuel Burner			Electrical			Catalyst		
	LHDDE	MHDDE	HHDDE	LHDDE	MHDDE	HHDDE	LHDDE	MHDDE	HHDDE
Burner Can	$21	$21	$21	-	-	-	-	-	-
Fuel Delivery System	14	14	14	-	-	-	-	-	-
Fuel Ignition System	35	35	35	-	-	-	-	-	-
Auxiliary Air System	64	64	64	$56	$56	$56	-	-	-
Exhaust Diversion System	64	67	73	64	67	73	-	-	-
Electronic Control System	71	75	75	71	75	75	$59	$62	$62
Electrical System	-	-	-	78	89	102	-	-	-
Catalyst Dispensor System	-	-	-	-	-	-	53	53	53
Catalyst	-	-	-	-	-	-	5	9	18
Catalyst System Exhaust Mods	-	-	-	-	-	-	33	42	71
Total	$269	$276	$282	$269	$287	$306	$150	$166	$204

EPA's estimated electrical heating system costs range from $78-$102, depending on HDDE size. The Agency believes these costs are representative of the type of electrical systems that are commercially viable in the 1990s. However, due to the current lack of information regarding specific designs, these cost estimates are subject to a significant degree of uncertainty. In discussions with various suppliers of electrical heating equipment, Mueller Associates identified several important uncertainties that could significantly affect the cost of the electrical system. These include the size and power requirements of the heating elements, ensuring adequate battery capacity for engine starting, and prevention of trap thermal stress due to uneven heating during regeneration. In response, Mueller Associates has estimated the potential cost of sophisticated electrical systems that address each of the potential areas of concern as suggested by its industry contacts. Such electrical systems could cost nearly four times more than that estimated by EPA. The Agency believes that such sophisticated systems will be found to be unnecessary as more information becomes available. Hence, only EPA's estimate will be used in this analysis.

As summarized in Table 3-33, electric regeneration systems are estimated to cost about $269, $287, and $306 for LHDDEs, MHDDEs, and HHDDEs, respectively.

Catalytic Regeneration System Costs - Unlike the other regeneration systems, which are at least conceptually well known, the catalyst and the technique which will be used to introduce it into the trap remains a matter of some conjecture. The approach assumed in this analysis involves onboard vehicle storage of a metallic compound in dry powder form. From time to time, a metered amount of catalyst is fluidized by compressed air from the vehicle's turbocharger and then injected into the exhaust stream just ahead of the trap to initiate combustion. This type of regeneration system is potentially the simplest with regard to the required hardware. The primary components consist of the catalyst, the catalyst dispensor system, and the electronic control system. As discussed in conjunction with the other regeneration systems, the requisite stainless steel exhaust pipe is treated as a part of the catalyst regeneration system.

The metallic catalyst is assumed to be copper in the form of powdered copper chloride (CuCl). The amount of catalyst required for new HDDEs is estimated to be about 2.3 pounds for LHDDEs, 4.0 pounds for MHDDEs, and 8.5 pounds for HHDDEs. This is based on the allowable maintenance intervals for each HDDE, the estimated fuel economies for these vehicles as described previously, and an assumed catalyst requirement equivalent to 0.16 g/gallon of diesel fuel.[14] Combining this with an estimated cost of $1.46/pound of CuCl,[8] the catalyst costs are estimated to be $5, $9, and $18 for LHDDEs, MHDDEs, and HHDDEs, respectively.

The catalyst dispenser system has several parts. A one gallon polyethylene bottle is used to hold the required powered catalyst. This is estimated to cost about $1 per vehicle.[7] The reservoir will be attached to a metering device with an integral agitator extending into the reservoir to break up lumps of catalytic material. This device is estimated to cost about $30 for each HDDE.[7] The metering device uses a small electric motor with an estimated cost of $12 per vehicle.[7] After being metered, the catalyst is fluidized and sprayed or injected into the exhaust using high pressure air. The fluidizer/injector unit includes the required fittings necessary to mate it to the metering device and air supply. The estimated cost is $7 per HDDE.[7]

The final components of this system are the hoses for transmitting the compressed air and fluidized catalyst. The Agency estimates the cost of these items at about $3 per vehicle.

The electronic control system requires four sensors. Three of these are the same as used by the other types of regeneration systems: trap temperature $5, engine temperature $1, and exhaust backpressure $17. An engine speed sensor is also used and has an estimated cost of about $5 per HDDE.[8] The electronic control unit requirements are again incremental to the existing capability, although the cost is somewhat less than for the other regeneration systems because the catalyst system is less complex. The incremental electronic control unit cost is estimated by EPA to be about $22 for all HDDEs. The wiring harness will also be less costly. This item is estimated by EPA at about $9 for LHDDEs and $12 for MHDDE and HHDDEs.

The standard steel exhaust pipe will be replaced with a stainless steel counterpart as with the other regeneration systems. However, the catalyst regeneration system should not require that the exhaust bypass the trap during the regeneration process. Therefore, the cost of the stainless steel pipe should include a credit for the deleted standard steel pipe. The incremental exhaust pipe cost for each HDDE size category is taken from the corresponding estimate used in the proposal, with one revision. As described in the DPS, the incremental exhaust pipe cost was based on the assumption that about 25 percent of the MHDDEs and HHDDEs would have dual exhausts. This assumption has been revised because essentially all MHDDEs and HHDDEs are expected to be equipped with turbochargers in the 1990's and, therefore, will likely have only one exhaust pipe. Making this revision, the estimated incremental cost of the stainless steel exhaust pipe is $33 for LHDDEs, $42 for MHDDEs, and $71 for HHDDEs.

As summarized in Table 3-33, catalyst regeneration systems are estimated to cost $150 for LHDDEs, $166 for MHDDEs, and $204 for HHDDEs.

Total Trap-Oxidizer Variable Costs -- Table 3-34 presents a summary of the three trap system costs. As shown, the ceramic monolith trap with a fuel burner regeneration system has an estimated cost of about $370 per LHDDE, $448 for MHDDE, and $574 per HHDDE. The ceramic monolith trap with an electric regeneration system has the potential of costing about the same as the ceramic monolith/fuel burner system. The ceramic fiber trap with a catalyst regeneration system could prove to be the least expensive trap-oxidizer with estimated costs of $223, $272, and $344 for LHDDEs, MHDDEs, and HHDDEs, respectively. As stated previously, the ceramic monolith/fuel burner trap-oxidizer will be used to determine the costs of the particulate standard, due to the greater uncertainty associated with the other designs.

Now that the variable costs for each HDDE size category have been determined, the average hardware cost for each trap equipped non-bus HDDE and urban bus, as well as that for the fleet-average vehicle can be calculated. This is done by combining information on sales and trap usage with the system cost for the appropriate HDDE class or classes. The methodology for deriving the various average costs is described below. This methodology will be used in this section for variable costs and in subsequent sections as required.

Identifying the variable cost for a trap-equipped urban bus is the most straight forward. Due to their horsepower ratings, all urban bus engines generally can be classified as MHDDEs. In addition, all urban bus engines will require a trap oxidizer to achieve the 0.1 standard. Therefore, the variable cost for the average urban bus is simply the value identified for MHDDEs, or $448 (Table 3-34).

The average cost for a non-bus HDDE with a trap oxidizer is found by sales weighting the system cost for each size category. As described elsewhere, total HDDE sales are composed of 35 percent LHDDEs, 29 percent MHDDEs, and 36 percent HHDDEs. However, bus sales must be removed from this distribution to find the percentage of sales in each category for non-bus HDDEs only. Urban bus sales are quite volatile from year to year, but would generally not exceed about 2 percent of total HDDE sales. Using this percentage and the fact that all urban bus engines are MHDDEs, the non-bus HDDE

Table 3-34

HDDE Costs for Trap-Oxidizer Systems

Size Category	Ceramic Monolith/ Fuel Burner			Ceramic Monolith/ Electrical			Ceramic Fiber/Catalyst		
	Trap	System	Total	Trap	System	Total	Trap	System	Total
LHDDE	101	269	370	101	269	370	73	150	223
MHDDE	172	276	448	172	287	459	106	166	272
HHDDE	292	282	574	292	306	598	140	204	344

sales account for 98 percent of the total and are distributed as follows: 36 percent for LHDDEs, 27 percent MHDDEs, and 37 percent HHDDEs. Therefore, sales weighting the various system costs with this distribution results in a variable cost for the average affected non-bus HDDE of $467.

The per vehicle cost when averaged over the entire fleet is the sum of the sales-weighted cost for an urban bus and the sales-weighted cost for the average non-bus HDDE (i.e., both trapped and untrapped). The urban bus component is simply 2 percent of the cost figure for a MHDDE. The non-bus component is 98 percent of the average non-bus cost. This average is determined by combining the various HDDE category costs with the non-bus sales distribution and the percentage of the non-bus fleet that is trap equipped. Expressed generically in equation form, the non-bus component of the fleet-average vehicle cost is:

Non-Bus Portion of Fleet-Average Cost =

(.98) X [$ per LHDDE x LHDDE Fraction) + ($ per MHDDE x MHDDE Fraction) + ($ per HHDDE x HHDDE Fraction)] x (Trap Fraction)

The last term in this equation adds some complexity to the calculation since the number of traps required for non-bus HDDEs is projected to change from about 70 percent in 1991, to about 60 percent in 1994 if the 0.25 were retained in that year. For ease of presentation, the non-bus cost component of the fleet-average vehicle will be evaluated as a short term value representing 70 percent traps and a long term value representing 60 percent traps. When these non-bus components are combined with the urban bus component, the result is the cost of a fleet-average vehicle in the short-term (1991) and the long-term (1994). The fleet-average cost for intervening years can be linearly interpolated. Using this methodology, the variable cost of the 1991 standards when averaged over the entire HDDE fleet is $329 in the short term and $284 in the long term.

iv. Total Manufacturers Cost of the 1991 Particulate Standards

The total undiscounted and discounted costs to manufacturers are shown in Table 3-35. The fixed costs are reproduced from Table 3-28. The variable costs are the products of the hardware cost per fleet-average vehicle and HDDE sales as shown in Table 3-10. The total undiscounted cost is $420.9 million, while the discounted cost is $402.6 million.

Table 3-35

HDDE Manufacturers' Cost for the 1991 Particulate Standards

Year	RD&T	Variable Cost	Undiscounted Total	Discounted* Total
1987	$8.0M	-	$8.0M	$11.7M
1988	20.0M	-	20.0M	26.6M
1989	14.0M	-	14.0M	16.9M
1990	7.5M	-	7.5M	8.2M
1991	-	$126.0M	126.0M	126.0M
1992	-	125.5M	125.5M	114.1M
1993	-	119.9M	119.9M	99.1M
			$420.9M	$402.6M

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* Discounted at 10 percent 10 1991.

b. Costs to Users for HDDEs Complying with the 1991 Particulate Standards.

i. First Cost

The amount that manufacturers must increase the price of each HDDE depends principally on the variable cost per vehicle, the number of vehicles over which the fixed costs will be apportioned, and on the cost of capital to the manufacturer. For the 1991 standards, it is assumed that manufacturers will generally recover their fixed costs prior to the effective date of the more stringent 1994 HDDE particulate standard. It is further assumed that the cost of capital is 10 percent. Hence, the first cost increase for a vehicle is the sum of a portion of the discounted fixed cost and the hardware cost, as described earlier.

In the short term the purchase price increment for trap-equipped non-bus HDDE is estimated at $457 for LHDDEs, $535 for MHDDEs, and $661 for HHDDEs. This averages $553 for a trap-equipped non-bus HDDE. The first price for an urban bus is $535. Expressed on a fleet-average basis, the cost would be about $390. In the long term, assuming a manufacturer continues to charge the same per vehicle for its fixed cost recovery, the fleet-average vehicle would cost an additional $336.

ii. Fuel Economy

In the draft economic impact analysis, non-bus HDDEs with traps were estimated to incur a 1 to 2 percent fuel penalty. Urban buses were assumed to incur a 2 percent penalty. As discussed in the Technical Feasibility Chapter, EPA's estimates generally fell within the range of fuel penalties that were presented in the few comments on this issue. Also as discussed in that chapter, the trap volumes in this final analysis have been significantly enlarged from those assumed in the proposal. As a result, the upper range of EPA's previous estimate has been revised downward from a 2 percent penalty to a 1.5 percent penalty. Therefore, the new range for non-bus HDDEs equipped with traps is 1.0-1.5 percent, while the new point estimate for urban buses is 1.5 percent.

Several important methodological changes have been made in calculating the fuel economy impact for each affected vehicle. For non-bus HDDEs, the estimated MPG values for each HDDE size category has been revised to reflect updated estimates. This was fully described in the previous discussion of the 1991 HDDE NOx standard where the discounted lifetime cost of a 1 percent penalty for each size category was shown to be the following: $54 LHDHEs, $259 MHDDEs, and $705 HHDDEs. Using this information, the 1.0-1.5 percent penalty represents a discounted lifetime cost of \$350-\$525 for the average non-bus HDDE equipped with a trap.

For urban buses, three key assumptions have been revised from the values used in the draft analysis. A recent EPA analysis shows the average annual bus mileage is about 45,000 miles rather than 50,000 miles, and that the average lifetime is closer to 12 years than 10 years.[3] These two changes are included in this updated analysis. The third change affects fuel costs for buses. The draft analysis utilized the same cost per gallon of diesel fuel for both non-bus and bus HDDEs, i.e., \$1.20/gallon. Diesel fuel for urban buses is actually significantly less costly than that for non-bus HDDEs due to volume discounts and lower taxes. A comment from the Department of Transportation supported the use of a \$1.00/gallon cost for urban buses. This value has been adopted for use in this analysis. Based on these revised values, the estimated 1.5 percent fuel penalty results in a discounted lifetime fuel cost of \$1070 for each urban bus. Expressed on a fleetwide basis, the average HDDE will incur a short-term fuel economy penalty of about \$261-\$381 and a long-term penalty of about \$227-\$330.

It should be noted that the above fuel economy penalties were estimated for trap-oxidizer systems using ceramic monolith substrates and fuel burners for regeneration. If these same traps were used with an electrical regeneration, the penalty would likely be about the same, due to the energy required by the alternator. However, if the ceramic fiber trap is used in the future, the fuel economy penalty would be somewhat less. The use of a catalyst to lower the ignition temperature of the collected particulate would avoid the use of energy intensive heating systems, since the traps would be self regenerating. In this case, the fuel economy penalty would be lowered by an amount that is basically equivalent to the energy used to regenerate the other two trap systems. EPA estimates this is equivalent to about a 0.5 percent fuel economy penalty. Therefore, the use of a ceramic fiber trap might result in only a 0.5-1.0 percent penalty rather than the 1.0-1.5 percent penalty used in this analysis.

iii. Maintenance

The draft analysis identified two maintenance items for trap-equipped HDDEs: the regeneration system and the exhaust system. The regeneration system was assumed to require maintenance after approximately five years of operation. At that point, the engine temperature and trap temperature sensor would need replacement. For the exhaust system, the customary replacement of the standard steel exhaust pipe was expected to be eliminated, because this component would be displaced by a stainless steel exhaust pipe as part of the trap-oxidizer system. Sensor maintenance when discounted to the year of vehicle purchase was estimated to range from $22 for LHDDEs with one trap to $44 for HHDDEs with two traps. A net savings was projected due to eliminating the need for exhaust pipe replacement. This discounted savings was estimated at $39 for LHDDEs, ranging up to $97 for HHDDEs.

Four general comments were received from metropolitan transit authorities and the Department of Transportation suggesting that maintenance costs would increase due to the combined NOx and particulate standards. Since the maintenance savings that were projected for trap-based particulate standards overwhelm the small cost associated with the NOx standards, these comments would appear to be directed primarily at the former standards. The New Jersey Bus Operations, Inc., specifically claimed that EPA's regulations will require the use of electronic control units, resulting in substantial expenditures for training, and the need for a more sophisticated and expensive labor force. In another specific comment, the Department of Energy estimated that the particulate standards could save up to $402 for a HDDE in Classes IIB-VI and up to $519 for a HDDE in Classes VII-VIII (undiscounted). Finally, a few manufacturers indicated in their technical feasibility comments that a trap may potentially require some type of maintenance during the vehicle's lifetime due to such things as the accumulation of ash or catalytic material.

In response to the concern expressed regarding the forced use of electronic control units on urban bus engines, electronics are projected to be widely used on all types of HDDEs in the future regardless of emission control requirements. Hence, costs associated with purported changes in the labor force cannot be charged against the emission standards. Concerning DOE's savings estimate and the general comments that maintenance costs will rise, EPA will address these comments by reevaluating the likely effect on maintenance in the context of the revised trap system design as described in the section on variable costs (i.e., ceramic monolith/fuel burner regeneration system).

The assumption in the draft analysis regarding sensor replacement was not adversely commented upon, and is being generally retained with a few revisions. The most significant changes are the use of new component costs and a revision in the assumed number of replacements for each HDDE size category. The estimated retail cost of each engine temperature sensor is $9 and each trap temperature is $20.[8] The replacement of both sensors is estimated to take one hour at

$28 per hour. To be consistent with the revised trap configuration, all HDDEs are assumed to have a single trap and, therefore, only one trap temperature sensor is required per affected vehicle. To account for the significantly different lifetime mileages of the various HDDE classes, the number of replacements over a vehicles life has been revised to one for LHDDEs, two for MHDDEs, and three for HHDDEs. Using these values and discounting the costs at 10 percent over the life of the vehicle, the approximate cost is $35 for LHDDEs, $57 for MHHDEs, and $71 for HHDDEs.

A review of EPA's previously estimated savings for exhaust pipes has resulted in this category being eliminated to be consistent with the revised ceramic monolith system design. Again referring to the description contained in the variable cost section, when the standard steel exhaust pipe is replaced by its stainless steel counterpart (i.e., from the manifold to the bypass valve), the displaced standard pipe is assumed to be roughly equivalent to that required by the bypass system (i.e., from the bypass to the muffler). For the purposes of this analysis, it is assumed that the replacement schedule of this standard pipe will be roughly equivalent regardless of location. Hence, no incremental maintenance is estimated for the exhaust system.

Regarding the possibility that traps could require some type of maintenance, estimating any cost in this area is especially difficult due to the current limited information on traps themselves. Nonetheless, to cover the potential costs of such a contingency, EPA will assume that trap maintenance will cost about $50 per event and that frequency of this maintenance will parallel sensor maintenance. Therefore, when discounted at 10 percent to the year of purchase, the cost is $31 for LHDDEs, $50 for MHDDEs, and $62 for HHDDEs.

Total maintenance costs for the average non-bus HDDE with traps is $102, while the cost for an urban bus is $107. On a fleetwide basis, the cost per HDDE in the short-term is $72 and declines in the long term to $62.

As in the fuel economy discussion, it is appropriate to examine the potential maintenance costs associated with the two other trap-oxidizer systems. The ceramic monolith/electrical regeneration system would have the same maintenance requirements and costs as the fuel burner, since the same trap substrate and sensors are used in both systems. If the ceramic fiber trap-oxidizer is used in the future, the maintenance requirements would be somewhat different. In addition to the costs associated with sensor and potential trap maintenance, catalytic material used in this system may need replacement during the vehicle's lifetime. Offsetting these costs would be a credit resulting from the use of the stainless steel exhaust pipe, which eliminates the need for periodically replacing the standard steel pipe. The discounted catalyst replacement costs, as estimated using the basic methodology presented in the variable cost section, are $14 for LHDDEs, $25 for MHDDEs, and $86 for HHDDEs. The discounted exhaust pipe credits, as estimated using the appropriate schedule for HDDV standard steel pipe replacements described in the DPS are $41 for LHDDEs, $51 for MHDDEs, and $81 for HHDDEs. Combining these values with those previously estimated for sensor and trap maintenance results in discounted ceramic trap maintenance costs ranging from $39 to $138 depending on HDDE size. For LHDDEs this is significantly less than the costs estimated for the ceramic monolith/fuel burner system, while for the largest HDDEs it is about the same.

iv. Total User Costs

The total cost to the purchaser of an HDDE is composed of the first price increase and the lifetime discounted costs for a fuel economy and maintenance. The cost for each trap-equipped non-bus HDDE is $577-604 for all LHDDEs, $901-1,030 for a MHDDE, and $1,499-1,852 for a HHDDE. For the average non-bus HDDE with a trap the total cost is $1,050-1,180. For an urban bus it is $1,712. Expressed as an average over the entire fleet, the total user cost in the short term is $723-843 and will decline to about $625-728 in the long term. The fleetwide cost per vehicle is summarized in Table 3-36.

6. Total HDDE Manufacturer and User Costs for the 1991 NOx and Particulate Standards

The total cost to HDDE manufacturers of the 1991 standards is the sum of the fixed and variable costs of the NOx and particulate emission control. These costs are passed on to the users of HDDVs as first cost increases, and are added to operating costs for total user cost of the standards. These values were developed above, and are presented in Tables 3-37 and 3-38.

The discounted manufacturer cost is about $476 million, while the average increase in lifetime user cost for a 1991 model year HDDV is $803-1,171, tapering off to $700-977 for a 1993 model year HDDV.

7. 1994 Diesel Particulate Standard (0.10 g/BHP-hr HDDEs)

In this section, the economic effects of the 1994 particulate standard for HDDEs are analyzed. The costs are examined as an increment to those that would result from

Table 3-36

Total User Cost
for the 1991 Particulate Standards

(Discounted to Year of Vehicle Purchase)

	Fleet Average Vehicle	
Cost Category	Short-Term	Long-Term
First Cost	$ 390	$ 336
Fuel Economy	261-381	227-330
Maintenance	72	62
Total	$723-843	$625-728

Table 3-37

Total HDDE Manufacturer Costs
1991 NOx and Particulate Standards

	Undiscounted		Discounted*	
	RD&T	Hardware**	RD&T	Hardware**
NOx	$28.7M	$42.3M	$34.8M	$38.5M
Particulate	49.5M	371.4M	63.4M	339.1M
Total	78.2M	413.7M	98.2M	377.6M
Grand Total	$491.9M		$475.9M	

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* Discounted at 10 percent to 1991

** Model year 1991-93 HDDVs.

Table 3-38

Total HDDE User Cost*
1991 NOx and Particualte Standards

	Short Term			Long Term		
	First Cost	Fuel Economy	Maintenance	First Cost	Fuel Economy	Maintenance
NOx	$68	$0-348	$0	$68	$0-174	$0
Particulate	$390	261-381	72	336	227-330	62
Total	458	261-729	72	404	227-504	62
Grand Total		791-1,259			693-970	

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* Incremental cost over cost of 1988 standards.

continuing the 1991 standard into the 1994 and later model years. As discussed in the Technical Feasibility Chapter, the Agency expects that the 1991 0.25 g/BHP-hr standard would require about 60 percent of the non-bus HDDEs to be trap equipped in the long term (i.e., about 1994). Similarily, the 1991 0.10 g/BHP-hr standard would require all urban bus engines to be trap equipped. With the more stringent 1994 0.10 g/BHP-hr, about 90 percent of the non-bus HDDEs will need traps, while the buses will all remain trap equipped. Therefore, the incremental effect and resulting cost of the 1994 standard is dependent on the use of an additional 30 percent traps by non-bus HDDEs.

The basic inputs for this analysis are taken from the 1991 particulate standards section where the costs of various trap-oxidizer systems were examined. Specifically, that analysis reviewed the costs associated with a ceramic monolith trap using a fuel burner regeneration system, a ceramic monolith trap using an electrical regeneration system, and a ceramic fiber trap using a catalyst regeneration system. The details of that comprehensive evaluation will not be repeated here. It is important to note, however, that only the ceramic monolith/fuel burner system was used to estimate the economic effects of the 1991 standards. This approach was taken, in spite of the potentially lower cost of the ceramic fiber/catalyst system, because the ceramic monolith/fuel burner trap is presently the most well defined and may be the first commercially available trap-oxidizer.

The economic effects of the 1994 standard will also be assessed using the costs associated with the ceramic monolith/fuel burner system. Due to the long leadtime associated with the 1994 requirement, however, it is possible that a lower cost trap oxidizer such as the ceramic fiber/catalyst system may be widely used by the effective date of the standard. If this were to occur, the cost of the 1994 standard would be somewhat less than that presented in the subsequent sections.

a. Cost to the Manufacturers

i. Fixed Costs

The total fixed cost of the 1994 standard obviously will be significantly less than that associated with the 1991 standards. Only 30 percent of the HDDEs will incur development and certification testing costs, compared to about 70 percent in 1991. Also, when reviewed on a per vehicle basis, it is reasonable to expect that engineering experience gained throughout the early 1990's will make the application of traps to new families in 1994 less difficult than it was in 1991.

Therefore, the fixed cost that was recovered in the sales price of a trap-equipped HDDE under the 1991 standards (i.e., about $87) would seem to represent an upper limit for the fixed cost associated with the 1994 standards.

Using this conservative assumption, the total fixed cost of the 1994 standards can be estimated by multiplying $87 per trap-equipped vehicle by the number of such vehicles over which fixed costs are recovered. As in the previous HDDE analyses, the fixed costs of a standard are assumed to be recovered over three years of production immediately following the effective date of the standard. The estimated cost of capital is 10 percent per annum. Based on the projected HDDE sales in Table 3-11, the number of trap-equipped HDDEs used in the fixed cost calculation is about 334,000 (i.e., 30 percent of the 1994 through 1996 HDDE "discounted sales," excluding buses). This results in total estimated fixed costs of $29.1 million, when expressed as a lump sum investment in 1994. The expenditures of these over time can be expected to occur as shown in Table 3-39.

ii. Variable Costs

The variable cost of a specific trap-oxidizer system is a function of vehicle size. The costs of a ceramic monolith trap with a fuel burner regeneration system was previously estimated at $370 for LHDDEs, $448 for MHDDEs, and $574 for HHDDEs. Total HDDE sales, excluding urban buses, are composed of 36 percent LHDDEs, 27 percent MHDDEs, and 37 percent HHDDEs. Using these values to sales weight the trap-oxidizer cost for each size category results in an average variable cost of $467 per trap-equipped HDDE. Expressed as an average over the entire fleet, the variable cost is $137 per HDDE.

iii. Total Manufacturers Cost of the 1994 Particulate Standards

The total discounted and undiscounted costs to manufacturers are shown in Table 3-40. The fixed costs are taken directly from Table 3-39. The variable costs are the products of the hardware cost per fleet-average vehicle and total HDDE sales in each specific year (Table 3-11). The total undiscounted cost is $193.5 million, while the discounted cost is $217.9 million.

b. Cost to Users for HDDEs Complying with the 1994 Particulate Standards

i. First Cost

The amount that a manufacturer must increase the price of an HDDE to recover its expenses depends on the timing of the costs, the cost of capital, and the number of vehicles over

Table 3-39

Total Fixed Cost of the
1994 HDDE Particulate Standard

Years	Discounted Fixed Costs[1]	Undiscounted Fixed Costs
1990	$ 5.0 M	$3.4 M
1991	13.0 M	9.8 M
1992	7.9 M	6.5 M
1993	3.2 M	2.9 M
Total	$29.1 M	$22.6 M

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[1] Discounted to the effective date of the standard, i.e., 1994.

Table 3-40

HDDE Manufacturers' Cost for the 1994 Particulate Standard

Year	Fixed Cost	Variable Cost	Undiscounted Total	Discounted Total
1990	$3.4 M	--	$ 3.4 M	$ 5.0 M
1991	9.8 M	--	9.8 M	13.0 M
1992	6.5 M	--	6.5 M	7.9 M
1993	2.9 M	--	2.9 M	3.2 M
1994	--	$56.0 M	56.0 M	56.0 M
1995	--	57.0 M	57.0 M	51.8 M
1996	--	57.9 M	57.9 M	47.8 M
Total			$193.5 M	$184.7 M

which the fixed costs will be recovered. As discussed in deriving the fixed costs, manufacturers are expected to recover fixed costs over the first three years of production. The cost of capital was also identified as 10 percent per annum. Hence, the first cost increase for a vehicle is the sum of a portion of the discounted fixed cost and the hardware cost, as described earlier. Using this methodology, the purchase price increment for a trap-equipped HDDE is estimated at $457 for LHDDEs, $535 for MHDDEs, and $661 for HHDDEs. This averages $553 per trap-equipped HDDE. Expressed on a fleetwide basis, the purchase price increase is about $163.

ii. Fuel Economy

Traps may adversely affect fuel economy due to a potential increase in exhaust backpressure and because of the energy required to initiate regeneration. The penalty associated with the use of this technology was estimated in the 1991 particulate standards discussion as 1.0-1.5 percent per trap-equipped vehicle. When discounted to the year of vehicle purchase, this is equal to approximately $54-81 for a LHDDE, $259-388 for a MHDDE, and $705-1,058 for a HHDDE. This amounts to $350-525 for the average trap-equipped HDDE. For the fleet-average HDDE, the discount lifetime fuel penalty is about $103-154.

iii. Maintenance

The potential maintenance costs associated with trap oxidizers fall primarily into two categories: sensor replacement and trap maintenance. The discounted lifetime costs associated with these items were estimated in the section on the 1991 particulate standards as being $66, $107, and $133 for a LHDDE, MHDDE, and HHDDE, respectively. For the average trap-equipped HDDE this is $102. Expressed on a fleetwide basis, the discounted lifetime maintenance increment is estimated $30.

iv. Total User Costs

The total cost to the purchaser of an HDDE is composed of the first price increase, and the discounted lifetime costs for fuel economy and maintenance. The total user costs for trap-equipped HDDEs complying with the 1994 standard are $120-147, $366-495, and $838-1,119 for HHDDEs, LHDDEs, and MHDDEs, respectively. For the average HDDE with a trap, the total cost if $1,005-1,181. Expressed as an average over the entire fleet, the total user cost is $296-347. The various fleetwide costs per vehicle are summarized in Table 3-41.

Table 3-41

Total User Cost for the
1994 Particulate Standard

(Discounted to Year of Vehicle Purchase)

Cost Category	Fleet-Average Vehicle
First Cost	$163
Fuel Economy	103-154
Maintenance	30
TOTAL	$296-347

8. Aggregate Costs to the Nation of the HDE NOx and Particulate Standards

The aggregate costs to the nation of the HDE NOx and particulate standards include the total manufacturer costs of RD&T and hardware, and user costs of fuel economy and maintenance which will be incurred due to the more strict emission control requirements of the standards. These costs were developed above, and are shown in Tables 3-42 and 3-43 according to the year of expenditure. All costs before the year of the standard are for RD&T, including certification, and costs after the year of the standard are for hardware and additional operating costs for the vehicles equipped with HDEs projected to be sold in those years.

The aggregate costs presented in Tables 3-42 and 3-43 for each model year group are incremental in nature. The aggregate incremental costs for the 1991 model year group represent only the added costs beyond those incurred in the 1988 model year group. The same is true in considering the 1994 model year group aggregate costs, with the exception that the increment is calculated relative to 1991.

All costs are shown undiscounted in Table 3-42 and discounted at 10 percent to the year of the standard in Table 3-43 and are developed in the preceding sections. As shown, the aggregate costs to the nation of the HDE NOx and particulate standards are approximately $118-600 million for the 1988 standards, $833-1,241 million for the 1991 standard, and $336-394 million for the 1994 particulate standards, discounted to each of those years.

D. Socioeconomic Impacts

The socioeconomic impact section in the Draft RIA discussed the effects on manufacturer sales and cash flow, the regional effects of employment, and the national effects on vehicle purchasers, energy usage, balance of trade, and inflation. These effects will not change significantly as a result of the reanalysis of costs, since cost estimates decreased or rose only slightly from the original estimates. However, some comments were received from citizens, environmental groups, the American Trucking Association (ATA), and public transit system operators concerning the socioeconomic impact of costs on individuals and organizations. The questions raised by these comments are reviewed in the following paragraphs.

Comments received from citizens and environmental groups argued that the cost of these regulations are rightly passed on to the consumers who also receive the benefits of improved

Table 3-42

Undiscounted Aggregate Incremental Costs of the HDE Standards

(millions of dollars)

Model Year 1988

Calendar Year	HDDE NOx	HDDE Particulate	HDGE NOx	HDE Total
1986	$18.0	$16.0	$1.6	$35.6
1980	12.7	7.0	2.1	21.8
1988	10.8-246.0	5.9	1.3	18.0-253.2
1989	11.2-195.5	6.2	1.3	18.7-203.0
1990	11.7-107.5	6.4	1.3	19.4-115.2

Model Year 1991

Calendar Year	HDDE NOx	HDDE Particulate	HDGE NOx	HDE Total
1987	-	$8.0	-	$8.0
1988	$7.0	20.0	-	27.0
1989	15.0	14.0	$3.5	32.5
1990	6.7	7.5	2.1	16.3
1991	13.7-146.6	253.9-299.8	2.8	270.4-449.2
1992	14.2-117.8	253.0-298.6	2.8	270.0-419.2
1993	14.4-84.5	239.8-282.4	2.8	259.0-369.7

Model Year 1994

Calendar Year	HDE Particulate
1990	$3.4
1991	9.8
1992	6.5
1993	2.9
1994	110.4-131.3
1995	112.3-133.6
1996	114.2-135.7

Table 3-43

Discounted* Aggregate Incremental Costs of the HDE Standards
(millions of dollars)

Model Year 1988

Calendar Year	HDDE NOx	HDDE Particulate	HDGE NOx	HDE Total
1986	$21.8	$19.4	$1.9	$43.1
1987	14.0	7.7	2.3	24.0
1988	10.8-246.0	5.9	1.3	18.0-253.2
1989	10.2-177.7	5.6	1.2	17.0-184.5
1990	9.7- 88.8	5.3	1.1	16.1- 95.2
Total	$66.5-548.3	$43.9	$7.8	$118.2-600.0

Model Year 1991

Calendar Year	HDDE NOx	HDDE Particulate	HDGE NOx	HDE Total
1987	--	$11.7	-	$11.7
1988	$9.3	26.6	-	35.9
1989	18.2	16.9	$4.3	39.4
1990	7.4	8.2	2.3	17.9
1991	13.7-146.6	253.9-299.8	2.8	270.4-449.2
1992	12.9-107.1	230.0-271.4	2.5	245.4-381.0
1993	11.9- 69.8	198.2-233.4	2.3	212.4-305.5
Total	$73.4-358.4	$745.5-868.0	$14.2	$833.1-1240.6

Model Year 1994

Calendar Year	HDE Particulate
1990	$5.0
1991	13.0
1992	7.9
1993	3.2
1994	110.4-131.3
1995	102.0-121.3
1996	94.3-112.1
Total	$335.8-393.8

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* 10 percent to the year of the standard.

environment and public health, and thus "will think that it is worth the cost." The Agency agrees with these comments. EPA expects the manufacturers to recoup their losses through first price increases in LDTs and HDEs.

On the opposite side of the argument, ATA believed that the costs may be too high, stating that, "at issue is not whether the average motor carrier will be adversely impact but rather, in the case of fuel penalties for example, the magnitude of this effect at the upper end of the range in potential penalties on the highest mileage group of single truck or small fleet owner/operators." In response, the Agency believes that the ATA has posed an unrealistic scenario. There is no reason to expect the maximum operating cost impact to fall on small high-mileage operators, since these operators will certainly search the market for the vehicles with minimal fuel economy impact if operating cost is of great concern. A comment by the National Resources Defense Council is relevant here, which states that, "even the more expensive standards still add only a small fraction to the initial cost and lifetime operating cost of the vehicles in question." Costs should be able to be easily borne by the trucking industry with small increases in the prices of consumer goods; since these costs will be carried by all segments of the industry, no one group should receive an unfair advantage or disadvantage due to the standards.

Several comments were received pertaining specifically to the socioeconomic impacts of the proposed NOx and particulate standards on urban transit buses. The Urban Mass Transportation Administration (UMTA) and local transit and transportation authorities from New Jersey, Washington, Chicago, Cleveland, Washington, D.C., Albany, and San Antonio all stressed the economic burden that would be placed upon urban transportation locally and nationally. There was general agreement among these agencies that EPA underestimated the true costs and economic burdens associated with the proposed standards. New Jersey Transit and VIA Metropolitan Transit in San Antonio indicated that the increased costs would be translated into higher fares, lower riderships, more personal vehicle use, and an increase in emissions as a net result of the proposed standards. Finally, the Chicago Transit Authority (CTA) expressed concern that engine selection for transit buses would be reduced as manufacturers leave the market due to the increased costs of control.

EPA has estimated the first price increase associated with a 0.10 g/BHP-hr particulate and 5.0 g/BHP-hr standard at a value of $644. The total fuel economy penalty resulting from these controls is estimated to be 2 percent, or $1427, in the long run, and slightly higher in the short run. There is also a maintenance cost of $107 per bus associated with the particulate standard. With the current average price of a diesel transit bus being $135,000-145,000, the first price increase estimated represents at most a 0.5 percent increase in the first price of a diesel transit bus. The operating and maintenance cost associated with an urban transit bus will rise at most slightly over 2 percent. This assumes that fuel is the only operating cost involved; other considerations would reduce this figure. Thus, the "economic burden" associated with the NOx and particulate standards does not appear to EPA to be severe. Based on this, EPA does not believe that there will be any significant fare increases and associated ridership losses attributable to the standards.

The market for diesel engines used in transit buses is small as CTA has indicated. Currently only one domestic manufacturer, GM, makes engines for large urban transit buses, and only one or two of their five such engines are made expressly for that purpose. Also, Caterpillar makes an engine used in smaller transit buses in some urban areas. EPA feels that it is highly unlikely that either manufacturer would relinquish its share of the market under such circumstances.

References:

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2. "Diesel Particulate Study," U.S. EPA, OAR, OMS, ECTD, SDSB.

3. "Heavy-Duty Vehicle Emission Conversion Factors 1962-1997," Mahlon C. Smith IV, EPA-AA-SDSB-84-1, August 1984.

4. "Standards for Emission of Particulate Matter From Diesel-Powered Light-Duty Vehicles and Light-Duty Trucks; Final Rule" (49 FR 14496, March 5, 1980).

5. "Standards for Emission of Particulate Matter From Diesel-Powered Light-Duty Vehicles and Light-Duty Trucks and Technical Amendment to Emission Regulations for Light-Duty Vehicles, Light-Duty Trucks, and Heavy-Duty Engines; Final Rule" (49 FR 3010, January 24, 1984).

6. Oral Communication with Terry Ullman, Southwest Research Institute, San Antonio, Texas, January 28, 1985.

7. "Cost of Selected Trap-Oxidizer System Components for Heavy-Duty Vehicles," Jack Faucett Associates and Mueller Associates, September 28, 1984.

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10. "Cost Estimations for Emission Control Related Components/Systems and Cost Methodology Description, Heavy-Duty Trucks," Rath & Strong, Inc., EPA-460/3-80-001, February 1980.

11. "Light-Duty Diesel Organic Particulate Control Technology Investigation," Southwest Research Institute, EPA-460/3-82-011, August 1983.

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13. "Preliminary Particulate Trap Tests on a 2-Stroke Diesel Bus Engine," Terry L. Ullman, Charles T. Hare, and Thomas M. Baines, SAE No. 840079, February 27, 1984.

14. Memo from Charles L. Gray, Jr. to Robert Maxwell, VW Request Regarding a Manganese Fuel Additive-Based Particulate Trap Regeneration System, U.S. EPA, OMS.

CHAPTER 4

NOx AND PARTICULATE ENVIRONMENTAL IMPACT

This chapter will examine the environmental effects which can be expected to result from the implementation of the revised NOx standards for light-duty trucks and heavy-duty engines and new diesel particulate standards for heavy-duty diesel engines. The material presented here begins with an overview of Chapters 4 and 5 in the Draft Regulatory Impact Analysis, followed by a summary and analysis of the comments made on the information contained in these chapters, and, finally, a presentation of revised projections of the environmental and air quality impacts of the NOx and diesel particulate emissions.

I. Overview of NPRM Analyses

A. Oxides of Nitrogen (NOx)

The Draft analysis opened with a brief review of the health effects associated with NOx emissions. The primary concerns reviewed were the human respiratory effects which formed the basis for the level of the primary ambient NO_2 standard. At the present time, this standard level is an annual arithmetic mean of 0.053 ppm.

Following this review, the effect of the proposed NOx standards on ambient air quality was estimated by comparing future year NOx emissions inventories and ambient NO_2 levels under three scenarios: 1) no future control, 2) the proposed standards, and 3) the eventual standards as mandated in the Clean Air Act. These analyses focused on those urban areas that are within range of exceeding the NAAQS by the end of the century. In addition, estimates of lifetime emission reductions per vehicle were made, primarily for use in the cost effectiveness analysis.

The air quality analyses for NOx were performed using a three-step approach. The first step involved the use of MOBILE2.5 to estimate emission factors by calendar year and vehicle class under the three scenarios. MOBILE2.5 determines emission factors in grams per mile (g/mi) for motor vehicles, based upon vehicle class, engine type, model year, and age of the vehicle. For heavy-duty engines, additional factors are used to convert brake-specific emission factors to g/mi emission factors. In order to obtain a specific calendar year emission factor for the individual vehicle classes, dieselization rates by model year, registration distributions by age, and mileage accumulation rates by age are combined with the emission factor by model year and age. The model year emission factors reflect improvements in control efficiency over time. The calendar year emission factors are then utilized by the EPA Rollback Model in step 3, described below.

In the second step, base year inventories of NOx emissions for the urban areas of interest were obtained from the National Emissions Data System (NEDS).[1] NEDS provides county-specific estimates of emissions by source category for each county in the United States. Total vehicle miles travelled (VMT) by county, VMT breakdown by vehicle class by county, and vehicle emission factors are the key parameters in determining the mobile source inventory. The 1981 NEDS inventory contained in the draft analysis was derived using emission factors from MOBILE2.

These were combined, along with current NO_2 levels and projected growth in source activities and control efficiencies, to yield future year emissions and NO_2 levels. This final step was performed using the EPA Rollback Model which begins with base year inventories of NOx emissions and base year ambient levels of NO_2 concentration (design values). Utilizing the emission factors from the MOBILE program, along with projections of total VMT by vehicle type, and similar numbers for stationary sources, the model can then project future year inventories of NOx emissions and corresponding ambient levels of NO_2. The emissions from the various sources are discounted to reflect their impact upon air quality in the immediate local area. Increases in ambient NO_2 levels are assumed to move linearly with increases in discounted NOx emissions.

Estimates of lifetime reductions in NOx emissions per vehicle were calculated in a straightforward manner. Differences in the emission factors by mileage for the various control scenarios and estimates of mileage accumulation over time for the appropriate vehicle classes (obtained from MOBILE2.5) were combined and summed over the vehicle's life.

A more complete description of the modelling procedures can be found in the Draft RIA, and in the following documents: "User's Guide to MOBILE2",[2] "Compilation of Air Pollution Emission Factors: Highway Mobile Sources",[3] and "Rollback Modelling: Basic and Modified".[4]

B. Particulate Matter

The Particulate Environmental Impact Chapter in the Draft RIA opened with a discussion of the relationship of diesel particulate matter to total suspended particulate and the NAAQS for particulate matter. The widespread non-attainment of the NAAQS in 1995, under either the current TSP standard or the proposed PM_{10} standard, was emphasized.

Following this discussion, the lifetime reductions in particulate emissions per vehicle were then derived, again for use in the cost-effectiveness analysis. These reductions were estimated using the same basic methodology as that described above for the NOx analysis.

Next, nationwide and nationwide-urban emissions of diesel particulate were presented. These projections were made using the same basic methodology as for NOx, but with slight modifications. For instance, due to the widespread violation of the particulate NAAQS, it is not reasonable to model each urban area individually. Thus, all U.S. urban areas were analyzed together. Also, the MOBILE model itself is not equipped to determine emission factors for diesel particulate matter, so it could not be used in the diesel particulate analysis. However, the concepts of MOBILE and all applicable parameters contained in MOBILE2.5 (described in detail in the Diesel Particulate Study, or DPS[5]) were used to estimate calendar year emissions.

Since the diesel particulate analysis is done on a nationwide, and not on an individualized urban area basis, NEDS is not used as the source for the base year inventories. Instead, emission factors were combined with estimates of nationwide urban VMT by vehicle class to develop base year inventories of diesel particulate emissions.

The estimates of nationwide emissions were then followed by projections of ambient diesel particulate levels. Due to the difficulties in distinguishing diesel particulate from others in atmospheric measurements, some measurable surrogate in the ambient air that is directly relatable to vehicular emissions must be used to estimate current ambient diesel particulate levels. The two surrogates that have historically been used are lead and CO. Three types of ambient impact were addressed: 1) levels expected to occur at air quality monitors, 2) average exposure levels of urban dwellers, and 3) ambient levels in selected high-exposure situations.

In estimating urban monitor-type levels, conceptually, historic ambient lead levels are first converted to historic ambient diesel particulate levels. This is done by assuming that the ratio of ambient concentrations of the two pollutants is equal to the ratio of their emissions, taking into account that a certain fraction of leaded particulate emitted falls out of the atmosphere very quickly and does not affect ambient air quality. Future ambient diesel particulate levels are then projected from historic levels using the general rollback approach. Projections were made for a broad spectrum of city sizes and meteorological conditions.

Annual average urban exposures, which include a variety of individual activity pattern effects, were based on a model developed by EPA to estimate exposures under various levels of the CO NAAQS. The model was based on measured exposures in specific types of situations in four U.S. cities, and involved placing the population into various cohorts which spend various amounts of time in each exposure situation. The CO levels projected by the model were converted to diesel particulate analogously to the conversion described above for the lead-surrogate model.

The high-exposure, or microscale, situations were analyzed using models developed for EPA for the projection of any completely dispersed, non-reactive pollutant. Thus, they are also based on the surrogate and rollback concepts. Four situations were modelled: roadway tunnels, street canyons, on an expressway, and nearby an expressway.

Following these three estimates of microscale concentrations of diesel particulate, the particular need to control diesel particulate at high altitude was discussed. While the lack of particulate emission data at high altitude prevented any more precise estimate of environmental impact than that presented in the nationwide analysis described above, Denver's air quality situation was discussed briefly and the need for high-altitude control was established.

Following these emission and air quality analyses, the Draft RIA attempted to put these projections in perspective by examining four classes of health and welfare effects associated with diesel particulate: 1) non-cancer health effects, 2) carcinogenic health effects, 3) visibility, and 4) soiling.

The analysis of non-cancer health effects associated with diesel particulate focused on identifying the potency of diesel particulate relative to that of general suspended inhalable particulate (i.e., PM_{10}). Using this relative potency, the ambient diesel particulate levels identified earlier were compared to the current PM_{10} levels of urban areas and the proposed PM_{10} standards.

With respect to carcinogenic effects, an estimate of the lifetime risk of contracting lung cancer from exposure to diesel particulate was made using estimates for the potency of diesel particulate and the earlier estimates of average urban exposure. Due to the limited epidemiological data available, the estimate of the carcinogenic potency of diesel particulate was made using a comparative potency method developed by EPA.[6] In this methodology, the relative potency of diesel particulate to known human carcinogens is determined from the relative potencies of the compounds in non-human laboratory bioassays and then applied to known human cancer risks of the human carcinogens.

As the size and chemical composition of diesel particulate makes it very effective in both scattering and absorbing light, a was developed to quantify the reduction in visibility caused by ambient diesel particulate levels in a large number of urban areas.[5] The model used the projections of ambient diesel particulate levels described earlier, Beers' law, a measured coefficient of extinction for diesel particulate, and the assumption that diesel particulate levels were constant inside the city radius and zero outside the radius to determine the visibility reduction.

The effects of soiling due to diesel particulate are described briefly in the Draft RIA. Little physical data were found describing the rate of particulate soiling or the soiling of diesel particulate relative to that of other types. However, due to its black color and oily nature, diesel particulate may have a disproportionate effect on soiling compared to the effect of other types of particulate matter. The only quantitative estimates of soiling were economic in nature and made in Chapter 8 of the Draft RIA (Cost-Benefit Analysis).

A more complete description of the methodologies described above can be found in the Draft RIA and the DPS.[5]

II. Summary and Analysis of Comments on NPRM Environmental Impact and Air Quality Projections

Numerous comments were received from vehicle and engine manufacturers, public transit organizations, environmental groups and private citizens, dealing largely with various specific inputs used to project future emissions and air quality in the NPRM analyses. Several of the issues addressed are common to both the NOx and diesel particulate analyses, and will be dealt with in the first part of this section. This discussion of common parameters will be followed by two sets of discussions dealing with factors specific only to the NOx and particulate projections, respectively.

A. Factors Common to Both Analyses

1. Baseline VMT Breakdown

A critical parameter in estimating both NOx and particulate emissions is the breakdown of VMT by vehicle class in the area being examined. These VMT breakdowns were under study by EPA just prior to the issuance of the NPRM. At that time, it was discovered that the VMT breakdowns used in the NOx projections, which were taken from the National Emissions Data System (NEDS)[1] for selected SMSAs, were quite different from the "Nationwide Urban" VMT breakdown used in the particulate analysis, which was developed primarily from the Energy and

Environmental Analysis, Inc. (EEA) fuel consumption model.[7] At the hearing following the NPRM, a technical report entitled "Motor Vehicle NOx Inventories"[8] was issued showing that the "Nationwide Urban" approach allocated a significantly lower percentage of total urban VMT to heavy-duty diesel vehicles (HDDVs) than did the NEDS methodology. Investigation into the NEDS method of county-by-county allocation of statewide VMT revealed some likely inaccuracies, especially with respect to an overestimation of HDDV VMT in urban areas. The suspected overestimation by NEDS was confirmed by estimates gathered from local transportation and planning authorities, which on average indicated a HDDV fraction of VMT very close to that estimated using the "Nationwide Urban" approach.[8]

Comments received on the base-year VMT breakdown used in the NOx projections and the above-mentioned technical report indicated support for the use of the local transportation agency data from each of the cities being modelled for NOx emissions. However, as the technical report explained, local data were available for only seven of the eleven cities in the NOx analysis. The use of updated 1981-83 average NO_2 design values (discussed below) resulted in the introduction of three new cities into the NOx analysis for which no local estimates have been obtained and the removal of two cities for which estimates were available. Thus, local data are now available for only a minority of the cities being modelled. To further complicate matters, subsequent analysis uncovered inaccuracies similar to those found with the NEDS approach in two of the seven available local estimates.[9]

Therefore, both the NOx and diesel particulate projections presented in this final rulemaking are based on VMT breakdowns by vehicle class developed using the "Nationwide Urban" approach, which are very similar to the average of the local data which are available and contain no known errors. This method provides the flexibility needed to accommodate ongoing changes in the cities being analyzed, yet addresses the largely non-urban nature of HDDV travel (an improvement over NEDS). Because the "Nationwide Urban" approach has been updated to be consistent with MOBILE3 (the model used is called the MOBILE3 Fuel Consumption Model)*, the breakdown of VMT by class is slightly different than that shown in "Motor Vehicle NOx Inventories"; however, the basic methodology and the urban fractions of VMT for each vehicle class are essentially the same, while only the nationwide VMT breakdown by vehicle class differs. In particular, the resulting HDDV fraction of urban VMT is essentially the same as that with the nationwide approach presented at the hearing and the average of the available local data. (Annual VMT by vehicle class, as estimated by the MOBILE3 Fuel Consumption Model and used in the final analyses, is presented in Table A-1 of the Appendix. The urban fractions of VMT used are shown in Tables A-2 and A-3 for heavy-duty diesel and gas vehicles, respectively.[10] Urban fractions of LDV and LDT travel are assumed to remain constant over time at 0.597 and 0.514, respectively, based on 1983 FHwA data.[11])

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* The MOBILE3 Fuel Consumption Model (M3-FCM) is a recently developed model, similar in principal to EEA's model, which estimates nationwide and urban VMT and fuel usage by vehicle class and fuel type. EPA's model is based primarily on MOBILE3 fleet characterization data (from NPTS and TIUS) and uses historic trends in vehicle registrations (from R.L. Polk) to project future VMT (mileage/vehicle assumed to be constant over time). Urban VMT fractions and gas/diesel sales splits used in the model are those presented in Tables A-2 through A-5 of the Appendix.

Final estimates of 1982 urban VMT breakdown by class, used in both the final NOx and diesel particulate analyses, are presented below:

Vehicle Class	% of Total 1982 Urban VMT*	
Light-duty Vehicle (LDV)	72.8	
- Gasoline		(71.2)
- Diesel		(1.6)
Light-duty Truck (LDT)	20.5	
- Gasoline		(20.1)
- Diesel		(0.4)
Heavy-duty Gas Vehicle (HDGV)	4.4	
Heavy-duty Diesel Vehicle (HDDV)	2.3	
Total	100.0	

These percentages, applied to 1982 VMT totals and then multiplied by 1982 NOx and diesel particulate emission factors, were used to develop base-year pollutant inventories for the emissions projections presented later in this chapter.

2. VMT Growth Rates

A modelling parameter that received a substantial amount of comment was the set of VMT growth rates that were applied to base-year VMT for each vehicle class to project future VMT. Specific recommendations concerning the appropriate levels of VMT growth were submitted by General Motors (with support from other manufacturers) and DOE (quoting EEA-based figures). Comments were also received from the American Trucking

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* Because of the use of updated NO_2 design values (to be addressed later in this chapter), an update from 1981 to 1982 base-year VMT was necessary.

Association (ATA), stating that future VMT by HDDVs will be reduced due to the replacement of some conventional truck-trailer combinations with twin trailers (i.e., one tractor pulling two trailers). Although ATA came to no final conclusion on an appropriate HDDV growth rate, Argonne National Laboratory was cited as a reliable independent source. As the Argonne VMT model (TEEMS) is being considered for use in the Federal government's National Acid Precipitation Assessment Project, and recent output of the model was available, Argonne's independent projections of future VMT growth are included for purposes of comparison in this analysis.[12]

In general, GM's estimates for each of the vehicle classes are lower than the growth rates used in the NPRM projections and lower than those recommended by both DOE and Argonne. Table 4-1 summarizes the VMT growth rates suggested by the commenters (along with Argonne), compared to the rates used in the NPRM analyses and those chosen for the FRM projections.

The final (FRM) growth rates shown in Table 4-1 are based on urban VMT projections made using the MOBILE3 Fuel Consumption Model (M3 FCM), calculated from the VMT figures shown in Table A-1. This is the same model used to develop the base-year urban VMT breakdown by vehicle class. The growth rates are nationwide averages for urban areas across the U.S.;* city-specific growth rates were not determined for the same reasons given earlier in the base-year inventory discussion -- absence of local projections from some cities and need to accommodate changes in the specific cities being modelled.

As Table 4-1 shows, the FRM (M3 FCM) growth rates for the LDV and LDT classes are in basic agreement with Argonne's independent projections, estimating LDT growth at a slightly higher level than LDV growth. The LDT growth rate is significantly lower than that used in the NPRM analysis, which was based on EEA's Eighth Quarterly Report.[13] GM's projections also show equal rates for LDVs and LDTs. However, their light-duty growth rates are significantly lower than the other estimates, most likely due to GM's assumption that both LDV and LDT VMT growths are primarily a function of growth in U.S. population. Although GM does state that there were adjustments made to account for trends in per-capita vehicle ownership and in miles driven by individual vehicles,[14] their approach still appears to underestimate future light-duty VMT growth in comparison with independent projections from both Argonne and EEA, based on more sophisticated econometric models.

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* In addition to urban VMT growth rates, nationwide growth rates were also calculated from the M3 FCM for use in the NOx analysis; both the urban and nationwide growth estimates are shown in Table A-7 of the Appendix.

Table 4-1
Annual Compound Urban VMT Growth Rates
(Percent per Year)

Vehicle Class	NPRM	EPA Interim Analysis	GM	DOE	Argonne	FRM
LDV	+1.7	+2.0	+1.2	--	+1.9	+1.9
LDT	+4.7	+4.0	+1.2	--	+2.3	+2.1
HDGV	-0.3	+2.1	-2.6	--	--	+0.6
HDDV	+6.4	+6.7	+3.6	+6.9	--	+4.2
HDV (overall)	--	--	+1.1	--	+2.0	+2.0

Note:

NPRM --	Based on EEA's Eighth Quarterly Fuel Consumption Model Report with assumptions; 1980-1995.
EPA Interim Analysis--	Based on EEA 10th Quarterly Report, with urban assumptions from TIUS and FHwA; 1981-1995.
GM --	Based on 1980 OBERS with assumptions; 1978-2000.
DOE --	Based on EEA data and projections; 1980-1995.
Argonne--	Based on ANL-83N forecast, TEEMS; NAPAP likely to be similar; nationwide estimates; 1980-2000.
FRM--	Based on MOBILE3 Fuel Consumption Model; 1982-2000.

With respect to overall heavy-duty growth, GM's estimate is based on 1980 Department of Commerce (DOC) OBERS projections for future growth in employment within the construction, manufacturing, and wholesale trade industries[15] and GM's is again significantly lower than the figure estimated by both Argonne and the M3 FCM. However, use of employment growth would again be expected to underestimate growth in VMT, since employment grows more slowly than economic output due to productivity improvements and heavy-duty VMT should more closely follow the latter. For instance, if GM had chosen growth in industry earnings (also included in DOC's projections) instead of jobs as an indicator of future heavy-duty travel, the new figure would be roughly 3.2 percent/year.[15] Thus, the FRM projections appear quite reasonable.

This overall growth rate for heavy-duty VMT must then be split between gasoline-powered and diesel-fueled vehicles (HDGVs and HDDVs, respectively). The MOBILE3 Fuel Consumption Model determines this split using diesel sales penetration rates developed along with MOBILE3,[10] the contents of which were critiqued by vehicle and engine manufacturers and other interested parties through a number of workshops.

3. Diesel Sales Projections

Manufacturers (primarily GM) recommended significantly lower future light-duty diesel sales fractions than those projected in the NPRM, suggesting 1995 model year diesel penetrations of 5 percent and 7 percent for LDVs and LDTs, respectively. These estimates compare to NPRM figures of 11.5 percent and 34 percent, respectively.

Future light-duty diesel penetration is difficult to predict, as the demand for diesels is very dependent upon future oil prices and the availability of diesel engines which satisfy consumer preferences. However, during the development of the MOBILE3 heavy-duty conversion factors, manufacturers (particularly GM) argued for substantial fuel economy improvements well through the 1990's, indicating a belief that fuel prices will indeed rise in the future calling for continued improvements in fuel economy. Therefore, to remain consistent with this position, growth in diesel penetration -- a fuel-saving technique -- was also projected to occur. EPA raised this issue at that time, indicating that substantial vehicle-related fuel economy improvements must logically be accompanied by increasing diesel usage. EPA accepted most of these fuel economy improvements predicted by the manufacturers, which lower heavy-duty emissions in the future without direct emission control. Thus, to argue for low diesel penetrations now is quite inconsistent with GM's position just a year ago and inconsistent with fuel economy improvements assumed in the derivation of the heavy-duty conversion factors.[10]

Therefore, model year diesel sales fractions used in the FRM analyses are similar to those estimated in the NPRM projections (post-1994 estimates of 11.5 and 34 percent for LDVs and LDTs, respectively), except that pre-1995 estimates have been reduced to reflect slowed growth (1990 projections of 5 percent and 15 percent, respectively). However, to identify the impact of potentially lower diesel penetration on particulate emissions, a sensitivity analysis will be performed wherein the 1990 penetrations (5/15 percent) are held constant through model year 2000 (results to be discussed in the final section of this chapter).* A complete listing of the light-duty model year diesel sales factions used in the FRM analyses is provided in Table A-4 of the Appendix.

While current light-duty diesel penetration is relatively low, particularly in light of GM's recent decision to withdraw from the market, the 11.5 percent 1995 LDV penetration is still realistic given that diesel penetration jumped from 0.3 percent in 1977 to 6.0 percent in 1981 with only one domestic manufacturer producing diesels. Given this fact, plus the potential volatility of world oil prices, it is not difficult to project a rapid increase in diesel sales if fuel prices were to increase dramatically. Furthermore, in the development of MOBILE3 and elsewhere, manufacturers have consistently predicted a continued need in the next decade to improve the fuel economy of their engines/vehicles, and EPA's diesel penetration rates are not inconsistent with these forecasts.

In view of the current (1983) level of diesel penetration into the LDT market -- approximately 8 percent -- and the fact that the diesel fraction of LDT sales has been steadily increasing since 1978, it is apparent that LDT diesels are a growth market. Given this, GM's estimate of 7 percent for 1995 seems unrealistically low, particularly since GM supports the need for future fuel economy improvements and does indeed predict growth in diesel penetration of all other markets (LDV and HDV classes). Therefore, 15 percent is a more realistic lower limit for the sensitivity analysis, maintaining a best estimate of 34 percent diesel penetration into the LDT market by 1995.

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* NOx emission factors for gasoline and diesel LDVs and LDTs are quite similar. Therefore, future NOx emissions are not sensitive to light-duty diesel penetration.

GM also commented on diesel penetration of selected heavy-duty classes, recommending 1995 figures of 25 percent and 52 percent for heavy-duty Classes III-V and VI, respectively. Although the NPRM analyses assumed slightly higher penetrations for these classes, the use of MOBILE3 for the final rulemaking projections implicitly assumes diesel fractions consistent with the heavy-duty conversion factors analysis;[10] these figures, also used as input to the MOBILE3 Fuel Consumption Model, essentially are in agreement with GM's estimates (30 percent and 53 percent for Classes III-V and VI, respectively). A complete listing of the final heavy-duty diesel sales fractions appears in Table A-5 of the Appendix.

4. Heavy-Duty Conversion Factors

A fourth issue -- heavy-duty emission conversion factors -- has been addressed extensively in the MOBILE3 workshops and documented in an August 1984 technical report.[10] No commenter brought any new information to bear in this area. As EPA has made known in the past,[16,17] MOBILE3 conversion factors for both HDGVs and HDDVs are significantly lower than those used in the NPRM analyses (based on MOBILE2.5). However, GM's contention that even further fuel economy improvements should have been incorporated (resulting in even lower emissions) appears inconsistent with their projections of low diesel penetration into the light-duty markets and slightly lower projections for the heavy-duty market. Therefore, the FRM analyses will continue to use the MOBILE3 conversion factors. (The final MOBILE3 conversion factors are presented in Table A-6 of the Appendix.[10])

5. Validity of Rollback Air Quality Models

The final issue common to both the NOx and particulate analyses is the validity of the "rollback" approach to predicting future air quality, where any change in emissions is assumed to translate proportionately into a change in ambient pollutant concentrations. In submitted comments, Ford (with support from MVMA) estimated that only one-fifth to one-third of the change in emissions due to VMT growth, not the entire change, should be applied to air quality projections; this estimate is based on area source dispersion modelling conducted by Ford.[18]

Investigation into Ford's urban analysis uncovered some assumptions which could have biased the results of the study. One, the traffic density (VMT/square mile) at the center of the city was assumed to remain constant. While VMT growth at city center is certainly more restricted than that at the outskirts, this assumption allows absolutely no consideration for urban redevelopment nor roadway construction or improvement.

Furthermore, the assumed model of VMT density forced most growth in VMT to be applied to the outer edges of the original urban area and to areas even beyond the original city radius, as the square of the city radius was increased in proportion to assumed emission growth.

Two, the choice of location for the two air quality monitors, when coupled with the above assumptions, also appears to minimize the impact of motor vehicles. The first monitor, located at city-center, would be primarily affected by the area just upward of city-center, where VMT growth has been assumed to be essentially zero. The second receptor, located 10 km directly downwind of city-center, would also be most affected by emissions in areas again assumed to experience little growth. Monitors not in line with the city-center, which were not included in the study, would be expected to experience more VMT growth than was assumed to be present in the more congested areas, and would therefore be more likely to demonstrate the impact of motor vehicle emissions.

An uncertainty present in Ford's urban dispersion modelling is the selection of only one stability class, "slightly unstable." As no information was given on the characteristics of this and other classes, it is difficult to assess the impact this choice had on the results.

EPA and others have used rollback modelling to project future air quality since the mid-1970's, and EPA has long approved its use in State Implementation Plans for projecting compliance. Validations of the rollback model as applied to carbon monoxide and lead were included in Chapter 3 of the Diesel Particulate Study;[5] and the figures presented there show a strong correlation between emissions and ambient concentrations over a decade. While dispersion modelling is probably more accurate, it is not feasible in terms of expense or time in a study such as this to evaluate every city using dispersion modelling. Instead, a simpler approach, such as the rollback model, must be used. Given the apparent bias and uncertainties in the Ford study, it would be inappropriate to discard or significantly adjust the rollback model here. However, possible improvements to the rollback approach, such as modified source discount factors, will be considered and could be incorporated into future modelling efforts if merited.

6. Significance of the Air Quality Impact

Many comments were received concerning the significance of the projected increases in urban concentrations of particulate matter and NO_2 due to truck emissions. MVMA and DOE questioned what portion of the future particulate ambient levels can be attributed to diesel trucks. The engine manufacturers also questioned whether the increases in NO_2 levels warrant the standards that have been proposed. The environmental interests, and most of the private citizens who chose to comment, uniformly criticized EPA for, in their impression, setting standards designed to hold emissions at current levels and not attempting to achieve net reductions.

The standards that have been established for both light- and heavy-duty truck NOx and heavy-duty diesel particulate have been based upon requirements of Congress, which primarily focus on technological feasibility and not only on environmental impact (the reader is referred to the Preamble to the final rule). For example, with respect to the particulate standards, the Act calls for the most stringent standards yielding "the greatest degree of emission reduction achievable through the application of technology which the Administrator determines will be available...giving appropriate consideration to the cost...and to noise, energy, and safety factors associated with the application of such technology." Thus, the availability of technology is the limiting factor -- not satisfactory environmental quality.

At the same time, the environmental impacts described in the Draft RIA, and below in Section III of this chapter, clearly justify the need for the standards being promulgated. Without these NOx standards, urban NOx levels would rise significantly over current levels by the early 1990's in low-altitude areas and even sooner in high-altitude areas. Even with these standards, growth in emissions is only being delayed until the late 1990's at low altitude and there is almost no delay of growth at high altitude. Nationwide NOx emissions from all sources will also grow substantially by the mid-1990's, even with substantial reductions from these standards. The case for the particulate standards is even stronger, given the widespread noncompliance with the current TSP NAAQS and that expected with the PM_{10} NAAQS (discussed later). Thus, the arguments that the standards are either too lenient or too strict based on environmental impact are not valid.

B. Factors Specific to NOx

1. Stationary Sources

Although no comments were made pertaining to the development of the stationary source inventories of NOx emissions, nor their projected growth, these were reviewed in light of what was discovered concerning the NEDS county specific estimates of mobile source VMT. The methodology used by NEDS to determine their inventories for stationary source

NOx were found to be acceptable.[19,20] Therefore, the NEDS inventories (updated to 1982) used in the NPRM air quality analysis will continue to be used here.

The growth rates associated with stationary source NOx used in the NPRM were determined for EPA by EEA in 1979. These were based upon certain population and industrial earnings growth factors as determined by DOC/OBERS in 1977.[21] These figures have been compared to those in the 1980 edition of OBERS,[15] and the growth factors do not appear to have changed significantly, so the same rates are being used here. A more detailed review of this issue will be performed in the near future as the National Acid Precipitation Assessment Program begins releasing its projections. (The final stationary source growth rates are presented in Table A-7 of the Appendix.)

2. NO_2 Ambient Design Values and Inclusion of California

A second issue specific to the NOx analysis is the set of NO_2 design values, or base-year ambient NO_2 concentrations, used in the air quality projections for selected cities. Commenters (Ford, MVMA) recommended the use of average concentrations over a 3-year period to minimize the effect of year-to-year fluctuations in monitored levels. This was in fact already being done, as interim air quality analyses conducted after completion of the NPRM analysis (early 1984) were based on NO_2 design values averaged over the period 1980-82. These design values are being updated once more for this analysis, as design values for the years between 1981 and 1983 are now available.[22]

With the adoption of updated design values, the specific cities that needed to be included in the NO_2 analysis (those with concentrations at or above 0.035 ppm -- 66 percent of the NO_2 NAAQS of 0.053 ppm) are different from those cities modelled in past studies. (Table A-8 of the Appendix lists the cities included in past and current NO_2 analyses, along with the NO_2 design values used in the air quality projections.) Also, as the monitoring period was updated to 1981-83, the base year changed to 1982 (the middle year); therefore, all base year emissions inventories for mobile and stationary sources (both discussed in previous paragraphs) used in the FRM analysis are now calculated for calendar year 1982.

As Table A-8 shows, California cities were not included in the NPRM NOx analysis, primarily because California vehicles are certified under different (more stringent) standards promulgated and enforced by the California Air Resources Board (CARB). However, CARB commented that many Federally-certified (non-California) line-haul trucks cross over California state lines and contribute to NOx and particulate emissions in California cities. Therefore, CARB feels that the impact of Federal heavy-duty engine standards on California air quality should be evaluated in the FRM. This is reasonable. Thus, CARB's projections of NOx emissions for the South Coast Air Quality Basin (SCAB), which includes the three California cities shown in the last column of Table A-8, are presented in the final section of this chapter.* (The inclusion of California cities in the diesel particulate analysis was not an issue, as all urban areas across the nation were modelled in aggregate; in addition, air quality projections were included for Los Angeles and San Diego in the DPS[5] and are included in the aggregate results presented in both the NPRM and the FRM.)

3. NOx Emission Factors

Some commenters recommended that MOBILE3 NOx emission rates be used instead of those in MOBILE2. This update was of course made, beginning with interim analyses conducted while the NPRM was being reviewed in early 1984.[23] For use here, the MOBILE3 inputs for post-1987 model year LDTs and HDEs were updated to apply specifically to the following two scenarios: 1) a "base case," which represents no further control of motor vehicle NOx (2.3 g/mi and 10.7 g/BHP-hr for LDTs and HDEs, respectively), and 2) a "controlled case," which evaluates the effect of the final standards promulgated in this rulemaking (1.2 and 1.7 g/mi for LDT_1 and LDT_2, respectively, and 6.0 followed by 5.0 g/BHP-hr for HDEs). The emission rates used in the FRM analysis are summarized in Tables A-9 and A-10 for low and high altitude areas, respectively; only those emission rates and assumptions that are different from MOBILE3 are provided.

It should be noted that the scenario designated as baseline (2.3/10.7) in the FRM analysis differs slightly from the baseline scenario presented in the NPRM or in MOBILE3. In the proposal, future HDDV NOx emission rates were assumed to remain at current levels (approximately 7.6 g/BHP-hr) even though the standard was set at 10.7. In preparing the FRM analysis, this previous assumption seemed unrealistic in light of the pressure that a particulate standard would put on NOx emissions, so the HDDV rates were instead adjusted upward assuming manufacturers would design for the 10.7 standard once they were sure it would remain at that level. Because the heavy-duty gasoline (HDGV) rates are currently well below the standard and the particulate standards do not apply to these vehicles, no adjustments to the previous assumptions for HDGVs were made.

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* Because EPA's MOBILE3 program does not have the capability to compute composite emission factors for California, CARB's NOx emissions and air quality projections were incorporated into the analysis.

4. Short-Term NO_2 Standard

The Natural Resources Defense Council (NRDC) commented extensively on the need for a short-term (3-hour) NO_2 standard. The NAAQS for NO_2 is currently under Agency review. The Agency is currently involved in extensive research concerning the potential need for such a standard. For the time being, however, it is EPA's opinion that the current annual standard for NO_2 provides adequate protection against both long- and short-term health effects associated with NO_2. As the basis for the standards being promulgated is technological feasibility, and not the limit of environmental need, the existence of a short-term NO_2 NAAQS should not affect this rulemaking, except to further justify the controls being implemented.

5. Ozone and Acid Precipitation

Another issue specific to the NOx analysis is the effect of NOx reductions on urban ozone and downwind sulfate concentrations. GM (with support from several other commenters) contends that a decrease in NOx emissions will cause urban ozone and downwind sulfate levels to rise. NRDC, however, disagreed with GM's view on ozone formation, citing various sources who maintain that NOx control (as well as HC control) is essential in the reduction of ozone levels. NRDC does suggest that an increase in urban NOx emissions may lower ozone levels locally (as GM contends), but it will also result in increased ozone concentrations downwind of the higher NOx emissions, merely delaying peak ozone formation.

The exact relationships between NOx and the other two pollutants are rather complex and have been the subject of a fair amount of controversy over the past decade. Numerous factors play a role in these relationships, including (specifically for ozone) the ratio of HC to NO_2 ambient concentrations, meteorological and topographical characteristics of the area, spatial location of the NOx reductions, and others. Therefore, the relationships could differ from one urban area to another. In addition, existing scientific studies of the NOx/sulfate and NOx/ozone relationships are limited, and their results have not yet been adequately reviewed or accepted by the scientific community. An EPA-sponsored study of the NOx/ozone relationship is currently underway; however, the results are not yet available and, in any event, are unlikely to support net increases in NOx emissions.

As will be shown in the final section of this chapter, the NOx standards promulgated in the final rule will prevent substantial growth in NOx emissions beyond current levels, but will not significantly decrease NOx emissions between 1982 and the 1995-2000 time frame. Therefore, since a large reduction in total NOx is not an issue here, no substantial increase in ozone or downwind sulfate is suggested. Also, the possibility of reducing ambient ozone or sulfate concentrations by allowing NOx emissions to increase significantly is not now considered a viable long-term option. To allow concentrations of one dangerous pollutant (NO_2) to increase in hopes of lessening other pollutant levels would not appear to be wise. Instead, EPA will most likely address the need for further ozone and sulfate control in the context of HC control strategies and acid precipitation policy.

Several other comments were received concerning the relationship between truck NOx emissions and acid precipitation. The general comment from the manufacturers is that controlling truck NOx emissions is an inappropriate way to control acid precipitation, since it only represents a small percentage of emissions producing acid precipitation. GM also cites the fact that nitrate is much less acidifying than sulfate.

Environmental groups (specifically NRDC) were, in their words, appalled at the lack of any reference to acid precipitation in the Draft RIA. They recognize that, overall, SO_2 has more importance in terms of acid precipitation, but insist that NOx cannot be ignored. NRDC refers specifically to the Western U.S., where NOx contributes over half of the acidity in precipitation, and to such seasonal events as the spring snowmelt, where nitrates dominate the acidity.

There has been a great deal of controversy over acid rain in recent years as to its causes and effects, primarily due to the complexity of the issue and the lack of substantial clear-cut data on the subject. Although knowledge of acid precipitation is incomplete, it is clearly becoming a problem over widespread areas of the country.

Although NOx emissions contribute only about a third of all acid deposition in the east,[24] they may have a disproportionately higher impact in terms of their effects. For example, nitric acid tends to become concentrated in the winter snowpack and is then released during the spring thaw, creating episodic "hot spots" of acidity which unfortunately tend to coincide with the spawning period for fish and the beginning of new growth for plant life.[24]

In contrast to the east, NOx is the predominant acid rain precursor in the western part of the United States. This is due primarily to the use of low-sulfur coal in western powerplants, which results in only 20 percent of annual U.S. SO_2 emissions being produced in the states west of the Mississippi River.[24]

Also, while SO_2 is primarily emitted from stationary sources, NOx production is a joint mobile source/stationary source problem. As will be shown below in Section III, motor vehicles are responsible for almost one-third of nationwide NOx emissions. In the absence of further controls for LDTs and HDEs, nationwide NOx emissions will increase by 23 percent between 1982 and 2000. With these controls, emissions will still increase 14 percent by 2000, but will be 8 percent lower than uncontrolled levels, which represents a significant reduction.

Thus, at this time, it cannot be concluded that motor vehicle NOx controls have no effect on acid precipitation. Nor can it be stated that such controls will play a large role in acid precipitation control policy. Identification of the most appropriate role for motor vehicle NOx control must wait for the completion of the in-depth evaluations of the formation, transport, and welfare effects of acid deposition which the Agency has underway. However, as the health effects associated with both current and future NOx emission levels justify the need for these standards, this rulemaking need not wait for the completion of the acid deposition studies.

6. Visibility Effects

NRDC commented that NOx can play a part in visibility degradation, either in the form of NO_2 gas or nitrate aerosols. They indicate that 31 percent of the light extinction attributed to mobile sources in Denver in 1980 was due to motor vehicle NOx emissions.

The effects of NO_2 on visibility were examined in the review of the NAAQS for nitrogen oxides.[25] The conclusion by EPA at that time was that, although NO_2 does have a visibility impact, the improvement in visual air quality to be gained by reducing NO_2 concentrations was uncertain at best. Due to this uncertainty, NOx-related visibility impacts have not been considered in this rulemaking. However, as the standards being promulgated in this rulemaking will reduce future NO_2 levels in the atmosphere from what they would have been, to the extent NO_2 affects visibility, future visibility should improve.

C. Factors Specific to Diesel Particulate

1. Health Effects

NRDC, along with other environmental groups, took issue with how EPA characterized the health effects due to diesel particulate matter. They agreed with the EPA's statement that the cancer risk due to diesel particulate matter is "significant," but emphatically disagreed with EPA's assessment of this risk as "small." NRDC also stated that "the proposal notice makes no mention of the non-carcinogenic health threat from fine particulate emissions."

On the other hand, GM and the American Trucking Association (ATA) questioned the adverse health effects of diesel particulate emissions. Citing studies by the British Medical Research Council on London bus garage workers, the conclusions of the National Research Council's Diesel Impact Study committee and some of their own studies, GM concludes that there is no definite evidence to implicate diesel emissions as a "serious cancer hazard." ATA feels that since "available evidence does not indicate that diesel exhaust particles cause human cancers," any reference to such "should be removed from the record." They also question EPA's use of relative potency analysis in determining the cancer risk associated with diesel particulate matter.

The non-carcinogenic effects of diesel particulate matter were detailed in both the draft RIA and the DPS.[5] These effects are compared to the effects for other inhalable particulate matter (PM_{10}, particulates less than 10 micrometers in diameter), which, as opposed to TSP, appear to be most directly related to adverse non-cancer health effects. Based on the available data, no clear differences in non-carcinogenic health effects between ambient PM_{10} and fine diesel particulate matter could be determined, though there is some possibility that diesel particulate may be somewhat more hazardous. Thus, when considering overall health impact, the effect of diesel particulate control on PM_{10} levels was used as the primary indicator. As the commenters submitted no new data to the contrary, this finding must stand.

The carcinogenic health effects associated with the diesel particulate matter were also detailed extensively in the Draft RIA and the DPS.[5] The studies on the London bus garage workers were reviewed in the DPS and analyzed independently by the EPA's Carcinogen Assessment Group. Flaws in the design of these studies caused them to be disqualified from further consideration in the DPS, and no new information has been brought to light to change that determination. Another epidemiological study is currently being conducted by Harvard University to evaluate the possible effect of diesel exhaust in U.S. railroad workers. This study, referred to by NRDC, is described in the DPS, and will be reviewed by EPA upon its completion.

EPA did base its determination of the potential cancer potency of diesel particulate upon a comparative potency analysis that assumes that the relative results of lower animal testing can be extrapolated to humans. While human epidemiological data are definitely preferred, this approach is not feasible until a reliable epidemiological study is available. Until then, the relative potency analysis remains the most reliable.

With respect to the estimated cancer risk, the approach was taken to objectively state the risk and compare it to others experienced by the populace. Given that the risk stated is a lifetime risk for exposure to 1995 ambient levels of diesel particulate, the risk does not stand out and call for control beyond that which is technologically feasible for diesels. However, at the same time, the risk is not negligible and does support the need for some degree of control.

There was one additional comment on EPA's use of the proposed PM_{10} NAAQS to assess the effect of diesel particulate emission control. MVMA feels that "it is completely inappropriate for EPA to anticipate a PM_{10} standard, which has not been promulgated." They cite this as an act of "pre-judgment and a compromise of free ideas."

The proposed standards for PM_{10} appear in the March 20, 1984 Federal Register, but have not yet been promulgated. Use of this proposed NAAQS was thought to have provided the most appropriate means of demonstrating the impact of diesel particulate control on human health, as the change to PM_{10} from TSP was proposed to more properly force control on those particles affecting health. The diesel standards being promulgated could just as easily have been based on the current TSP standards. Justification of the light-duty diesel particulate standards was based on the TSP standards, and noncompliance with the TSP NAAQS is projected to be more widespread than with the PM_{10} standards.* Thus, use of the proposed PM_{10} standards provides another perspective from which to assess the need for particulate control and does not affect the result: diesel particulate control is justified environmentally. The aspect affected is the precision to which that need, and the effect of control, is identified.

2. Visibility Effects

Several comments were received pertaining to the visibility impacts of diesel particulate matter. Based upon a study of four cities, GM concluded that no significant impacts on visibility due to increased diesel particulate concentrations will occur except under strict NOx controls (1.0 g/mi for LDV, 1.2 g/mi for LDT, and 4.0 g/BHP-hr for HDE). They appear to have set a 5 percent reduction in visibility as the cutoff for "significant impact." NRDC, the Colorado Department of Health, and several private citizens mentioned their concern about visibility, especially in the Western U.S. NRDC emphasized that the reductions in visibility given were only averages, and that on many days the effect could be much worse than indicated.

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* Between 105 and 329 counties are projected to be in non-attainment of the proposed PM_{10} standard, compared to 300-525 counties estimated to be in non-compliance with the current TSP standard in the 1987-89 timeframe.[26]

The methods by which the EPA estimates the visibility impact due to diesel particulate matter are described in detail in Chapter 4 of the DPS.[5] These estimates are highly dependent upon the projections of diesel particulate emissions. EPA and GM differ substantially in this respect as is indicated by the analysis of other GM comments earlier in this chapter. In the case of the four cities modelled: New York City, Los Angeles, Washington, DC, and Denver, GM chose not to project any VMT growth except for Denver. Also, a fundamental difference lies in the value used for the critical level of contrast against background required to determine visibility. EPA used a value of 5 percent at airport sites for reasons described in the DPS. If similar modelling techniques are assumed (i.e., Beers' Law), GM's value is closer to 0.14 percent, which is well beyond the level of contrast discernable by the human eye. Correcting for some of these differences and considering the NOx standards being promulgated, the differences in the resulting estimates of the visibility impacts can be readily explained.

The projected reductions in visibility due to diesel particulate are annual average reductions, and it is likely that the effects will be greater on some days and less on others. However, the level of sophistication of the model and input data do not allow shorter term effects to be estimated accurately.

3. Soiling Effects

A few comments were received concerning the impacts of soiling due to diesel particulate matter. NRDC, in particular, cites estimates of economic costs due to soiling ranging from hundreds of millions to billions of dollars annually. EPA has reviewed the scientific and economic literature pertaining to soiling from particulate matter in general, and diesel particulate matter specifically. The estimates of the benefits from reduced soiling due to diesel particulate control shown in Chapter 8 of the Draft RIA were in the same range as the estimates quoted by NRDC. Therefore, there is general concurrence on this issue.

III. Emissions/Air Quality Projections

Both in response to the comments analyzed in Section II and as part of the ongoing process of re-evaluation and improvement of EPA's modelling efforts, EPA has revised its projections of future NOx and diesel particulate emissions and air quality. Several of the input parameters to EPA's models were revised with the adoption of MOBILE3,[27] and as mentioned earlier, the comments received on the emissions and air quality model inputs were also given full consideration in the development of final estimates for each parameter.

This final section of the chapter presents these revised projections, based on EPA's current best estimates for each of the various input parameters. Section A will deal with the NOx projections, followed by a discussion of the diesel particulate analysis in Section B. In both analyses, the methodologies and inputs are the same as those used in the NPRM analyses, except for the input changes discussed in Section II (and detailed in the Appendix). For information on the methodologies used, the reader is referred to Section I of this Chapter and also to the Draft RIA and the DPS.[5]

A. NOx Analysis

Projections of future NOx emissions and related air quality both with and without the promulgated LDT and HDE standards are presented below. First, the NOx analysis focuses on emissions in key urban areas (low-altitude, high-altitude, and California), and then moves to projections of nationwide NOx emissions. The third part of the NOx analysis deals with the impact of future emissions on ambient NO_2 levels in the urban areas of concern, and a final section offers EPA's conclusions on the need for future NOx controls.

1. Emissions in Key Urban Areas

As mentioned above, the first part of the NOx analysis focuses on the ten urban areas shown in Table A-8 of the Appendix, consisting of eight low-altitude and two high-altitude cities. Also, CARB's projections for the three California cities shown in the table (all located in the South Coast Air Basin) are included in this discussion.

Table 4-2 presents base-year and future NOx emissions inventories for the low- and high-altitude cities under two future NOx standards scenarios. "Base case" represents no further control of NOx, with a LDT standard of 2.3 g/mi and a HDE standard of 10.7 g/BHP-hr. The "controlled case" refers to the NOx standards being promulgated -- 1.2 g/mi and 1.7 g/mi for the LDT_1 and LDT_2 classes, respectively, and HDE

Table 4-2

Base-year and Future Urban NOx Emissions*

(1000 tons/year)

Eight Non-California Low-Altitude Urban Areas**

		1995		2000	
Source	1982	Base	Controlled	Base	Controlled
LDV	281	203	203(0%)***	220	220(0%)***
LDT	114	126	105(17%)	131	100(24%)
HDGV	42	39	35(10%)	40	34(15%)
HDDV	82	146	84(42%)	171	89(48%)
Others	291	352	352(0%)	381	381(0%)
Total	810	866	779(10%)	943	824(13%)

Two Non-California High-Altitude Urban Areas**

		1995		2000	
Source	1982	Base	Controlled	Base	Controlled
LDV	18.6	18.6	18.6(0%)***	20.3	20.3(0%)***
LDT	7.5	11.4	9.4(18%)	12.1	9.2(24%)
HDGV	2.6	2.8	2.5(11%)	3.0	2.5(17%)
HDDV	7.5	13.3	7.7(42%)	15.6	8.1(48%)
Others	38.5	47.3	47.3(0%)	51.5	51.5(0%)
Total	74.7	93.4	85.5(8%)	102.5	91.6(11%)

---

* NOx emissions do not include those from stationary point sources, due to limited air quality impact relative to ground-level sources.

** Includes the eight low-altutude and two high altitude SMSAs listed in Table A-9 (FRM column).

*** Numbers in parentheses represent reductions from base case.

standards of 6.0 g/BHP-hr in 1988, followed by 5.0 g/BHP-hr in 1991. Stationary area and off-highway source NOx emissions are included in the category "Others." In these urban projections, stationary point source emissions are not included because of their relatively low air quality impact per ton compared to that of ground-level sources.

As shown, total baseline NOx emissions in the eight low-altitude urban areas are expected to grow by seven percent between 1982 and 1995, with an overall increase of 16 percent by the year 2000. As in the NPRM, the largest increase is projected for the HDDV class, with year 2000 emissions more than double the 1982 levels. LDT emissions increase by approximately 15 percent, while HDGV and LDV emissions decrease without further control. (Shown graphically in Figure 4-1.)

The effect of the final standards for LDT and HDE NOx emissions in these eight low-altitude areas is also evident from the projections in Table 4-2. As shown, controlled NOx emissions are estimated to be approximately 10 percent lower than the base case in 1995, and 13 percent lower in the year 2000. These reductions due to stricter LDT and HDE NOx control result in total NOx emissions (including those from stationary area and off-highway sources) staying fairly constant through the year 2000. Total emissions decrease by 4 percent in 1995 relative to 1982, and are roughly 2 percent higher than base year in 2000, with motor vehicle emissions 18 percent lower in 1995 and 15 percent lower in 2000 (with respect to 1982 emissions). (See Figure 4-2.)

As shown in the bottom portion of Table 4-2, future emissions growth in the high-altitude areas is projected to be much greater than in the low-altitude cities. The difference is not VMT growth, as the same national average rates were used for both low and high-altitude areas; instead, growth is higher because the 1.0 g/mi NOx standard on 1981 and later model year cars (LDVs) and the 2.3 g/mi standard on LDTs (beginning in 1979) did not have as great an impact on high-altitude emissions as they did at low altitude. This is due to the fact that pre-control emission rates for LDVs and LDTs in high-altitude areas were lower than those in low altitudes but controlled levels are about the same. Therefore, the smaller impact of existing light-duty controls on high-altitude vehicles does not outweigh the future VMT growth, as it does in low-altitude areas. This is shown in Table 4-2, where base-case LDV emissions show a decrease between 1982 and 1995 in the low- altitude areas, but stay the same in high altitudes.

Overall, total baseline NOx emissions in the two high-altitude areas are projected to grow by 25 percent between 1982 and 1995 (shown in Figure 4-3), compared to 7 percent in standards of 6.0 g/BHP-hr in 1988, followed by 5.0 g/BHP-hr in 1991. Stationary area and off-highway source NOx emissions are included in the category "Others." In these urban projections, stationary point source emissions are not included because of their relatively low air quality impact per ton compared to that of ground-level sources.

As shown, total baseline NOx emissions in the eight low-altitude urban areas are expected to grow by seven percent between 1982 and 1995, with an overall increase of 16 percent by the year 2000. As in the NPRM, the largest increase is projected for the HDDV class, with year 2000 emissions more than double the 1982 levels. LDT emissions increase by approximately 15 percent, while HDGV and LDV emissions decrease without further control. (Shown graphically in Figure 4-1.)

The effect of the final standards for LDT and HDE NOx emissions in these eight low-altitude areas is also evident from the projections in Table 4-2. As shown, controlled NOx emissions are estimated to be approximately 10 percent lower than the base case in 1995, and 13 percent lower in the year 2000. These reductions due to stricter LDT and HDE NOx control result in total NOx emissions (including those from stationary area and off-highway sources) staying fairly constant through the year 2000. Total emissions decrease by 4 percent in 1995 relative to 1982, and are roughly 2 percent higher than base year in 2000, with motor vehicle emissions 18 percent lower in 1995 and 15 percent lower in 2000 (with respect to 1982 emissions). (See Figure 4-2.)

As shown in the bottom portion of Table 4-2, future emissions growth in the high-altitude areas is projected to be much greater than in the low-altitude cities. The difference is not VMT growth, as the same national average rates were used for both low and high-altitude areas; instead, growth is higher because the 1.0 g/mi NOx standard on 1981 and later model year cars (LDVs) and the 2.3 g/mi standard on LDTs (beginning in 1979) did not have as great an impact on high-altitude emissions as they did at low altitude. This is due to the fact that pre-control emission rates for LDVs and LDTs in high-altitude areas were lower than those in low altitudes but controlled levels are about the same. Therefore, the smaller impact of existing light-duty controls on high-altitude vehicles does not outweigh the future VMT growth, as it does in low-altitude areas. This is shown in Table 4-2, where base-case LDV emissions show a decrease between 1982 and 1995 in the low- altitude areas, but stay the same in high altitudes.

Overall, total baseline NOx emissions in the two high-altitude areas are projected to grow by 25 percent between 1982 and 1995 (shown in Figure 4-3), compared to 7 percent in

Figure 4-1

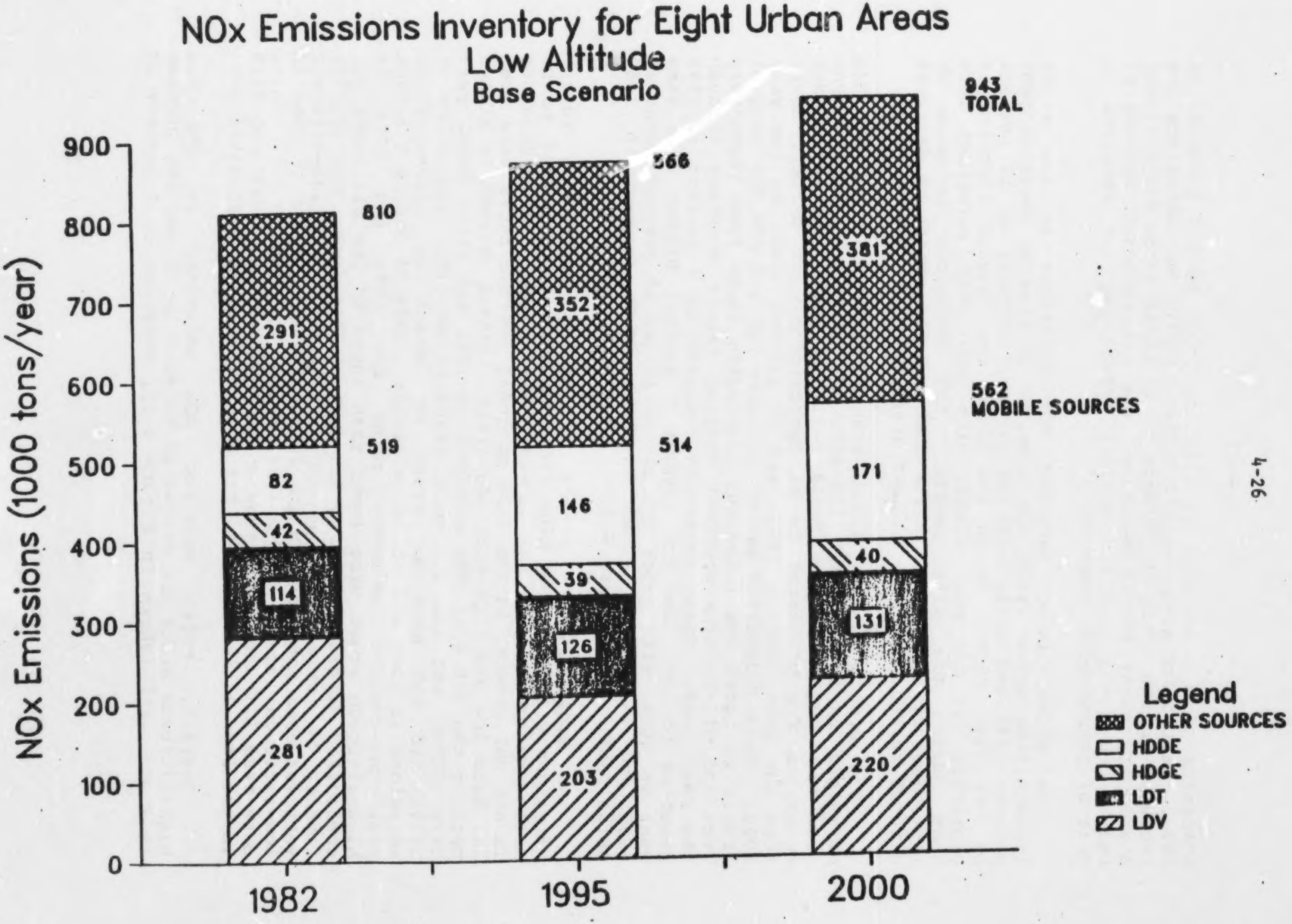

NOx Emissions Inventory for Eight Urban Areas
Low Altitude
Base Scenario
NOx Emissions (1000 tons/year)
900
800
700
600
500
400
300
200
100
0
1982
1995
2000
810
519
291
82
42
114
281
866
514
352
146
39
126
203
943
TOTAL
562
MOBILE SOURCES
381
171
40
131
220
Legend
OTHER SOURCES
HDDE
HDGE
LDT
LDV

Figure 4-2

NOx Emissions Inventory for Eight Urban Areas
Low Altitude
1.2/1.7/6.0/5.0 Scenario

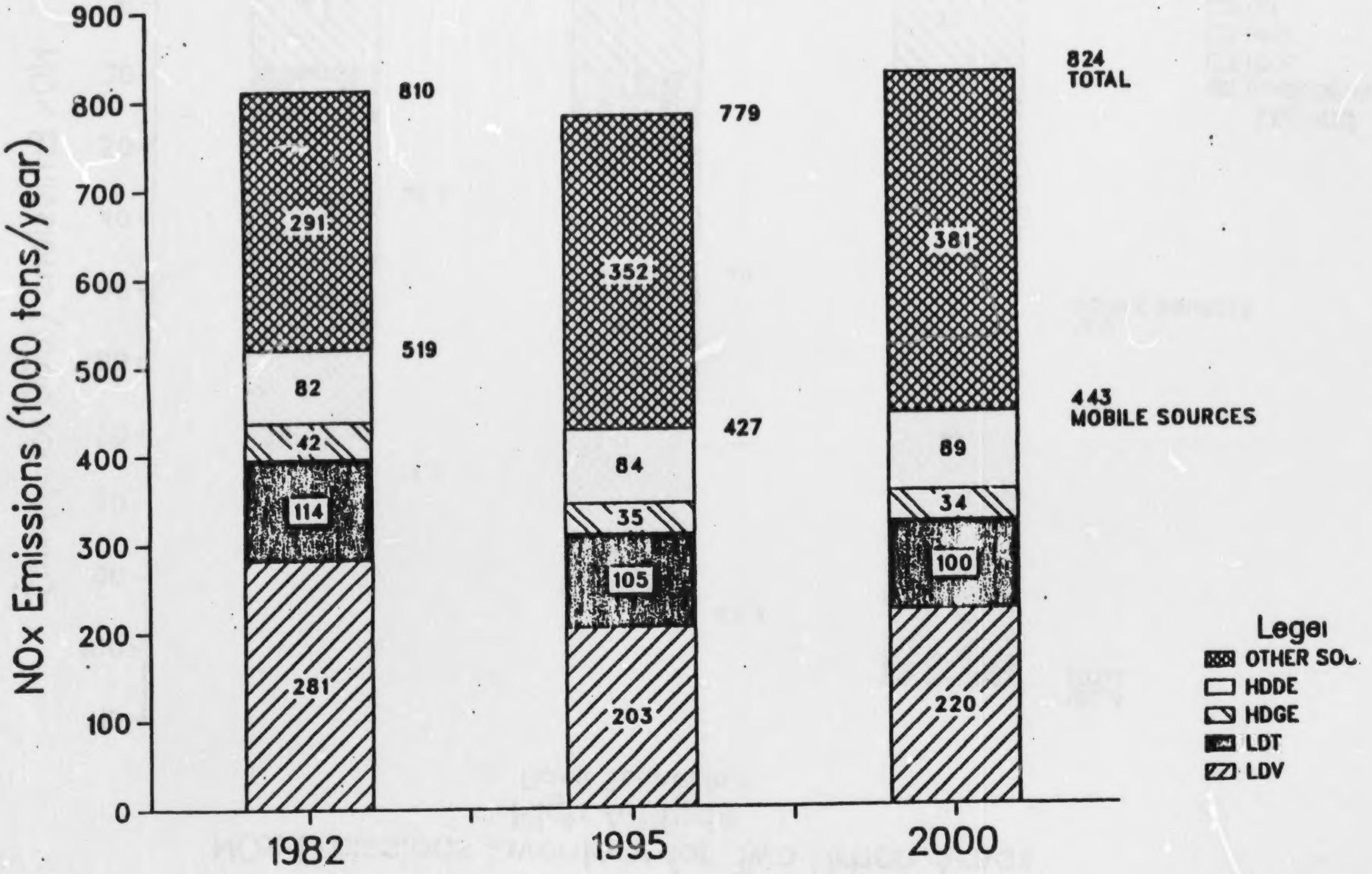
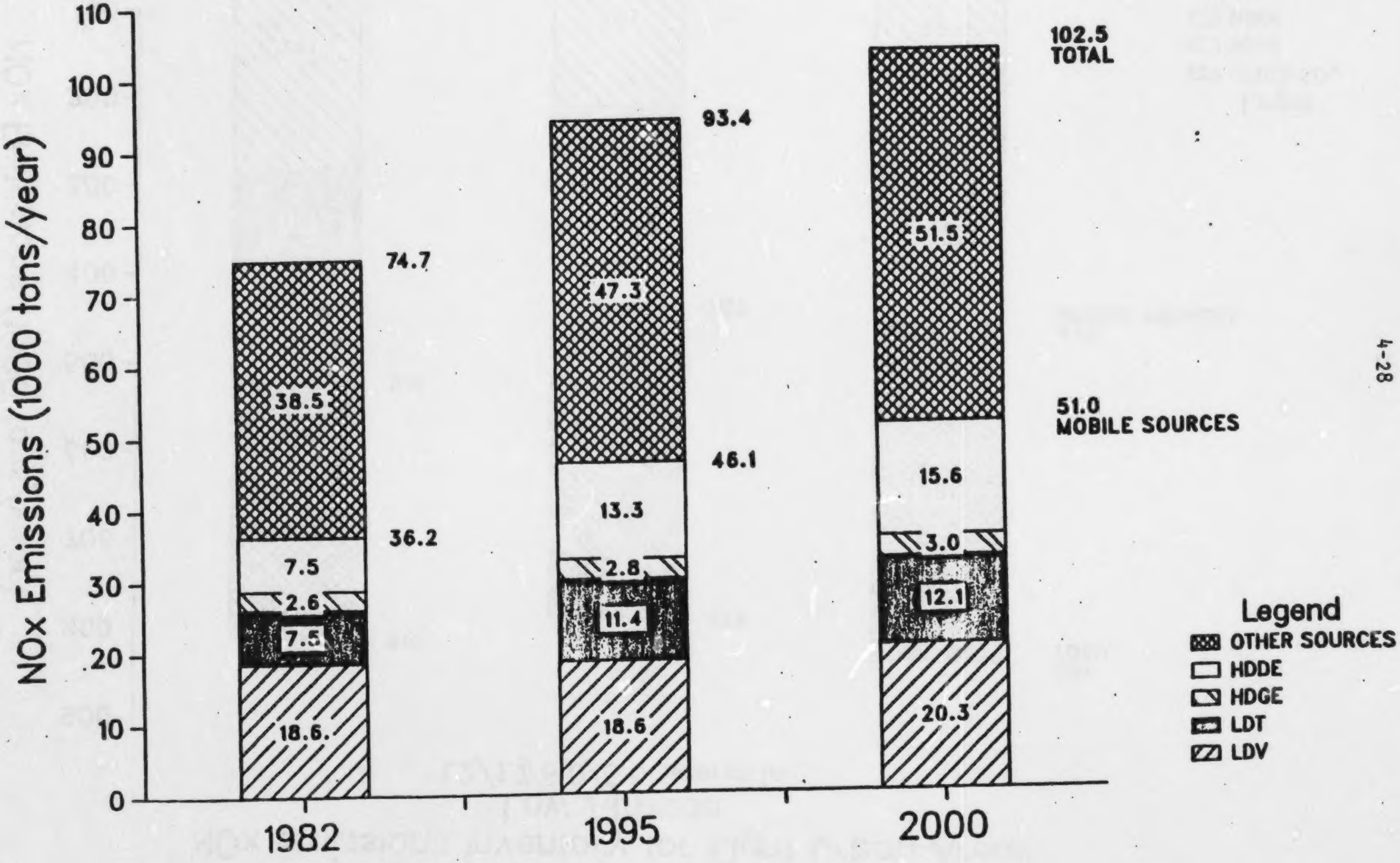


Figure 4-3

NOx Emissions Inventory for Two Urban Areas
High Altitude
Base Scenario



low altitudes. However, the promulgated LDT and HDE NOx standards have basically the same effect on 1995 and 2000 emissions in both altitudes. This is expected because, by that time, as mentioned above, the baseline (2.3/10.7 standards) emission rates in low and high altitudes are quite similar. But even with the stricter control on LDTs and HDEs, high-altitude emissions are expected to grow by 14 percent between 1982 and 1995, with a 23 percent increase by the year 2000 (see Figure 4-4). These figures are quite large compared to the relatively small changes from base-year levels projected to occur in low-altitude areas with the added control.

Projections of future NOx emissions for the South Coast Air Basin (the Los Angeles area) were provided by the California Air Resources Board (CARB) and are presented in Table 4-3. CARB examined three NOx standards scenarios for Federal line-haul (Class VIIIB) diesel trucks: 10.7 g/BHP-hr (no further control), 6.0 g/BHP-hr in 1988, and finally the 6.0 standard followed by 4.0 g/BHP-hr in 1991.* Although the Federal standard of 5.0 being promulgated in the final rule was not specifically examined by CARB, sufficient data was provided to interpolate between scenarios. All scenarios assume that only Federal line-haul trucks will cross into California (i.e., none of the lighter classes).

As Table 4-3 shows, total NOx emissions (including stationary point sources) in the SCAB are projected to be lower than current levels in the year 2000, regardless of Federal control. However, based on the California State Implementation Plan (SIP), total SCAB emissions must be at or below 895 tons/day in order for the cities in the basin to be in attainment of the NO_2 NAAQS. CARB projects attainment to be achieved sometime in the late 1980s, but projects non-attainment by 2000 due to growth unless Federal (and thus California) engines are certified at 4.0 g/BHP-hr. However, (though not modelled by CARB) a Federal standard of 5.0 g/BHP-hr may result in only marginal non-attainment, based on evaluation of the relative emission totals presented in Table 4-3.

2. Nationwide Emissions

In addition to evaluating the effect of the final standards on NOx emissions in these specific low-altitude, high-altitude and California urban areas, the impact on total

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* Due to provisions of California's waiver from Federal standards, this Federal truck scenario also assumes the reduction of California's standard from 5.1 to 4.0 g/BHP-hr.

Figure 4-4

NOx Emissions Inventory for Two Urban Areas
High Altitude
1.2/1.7/6.0/5.0 Scenario

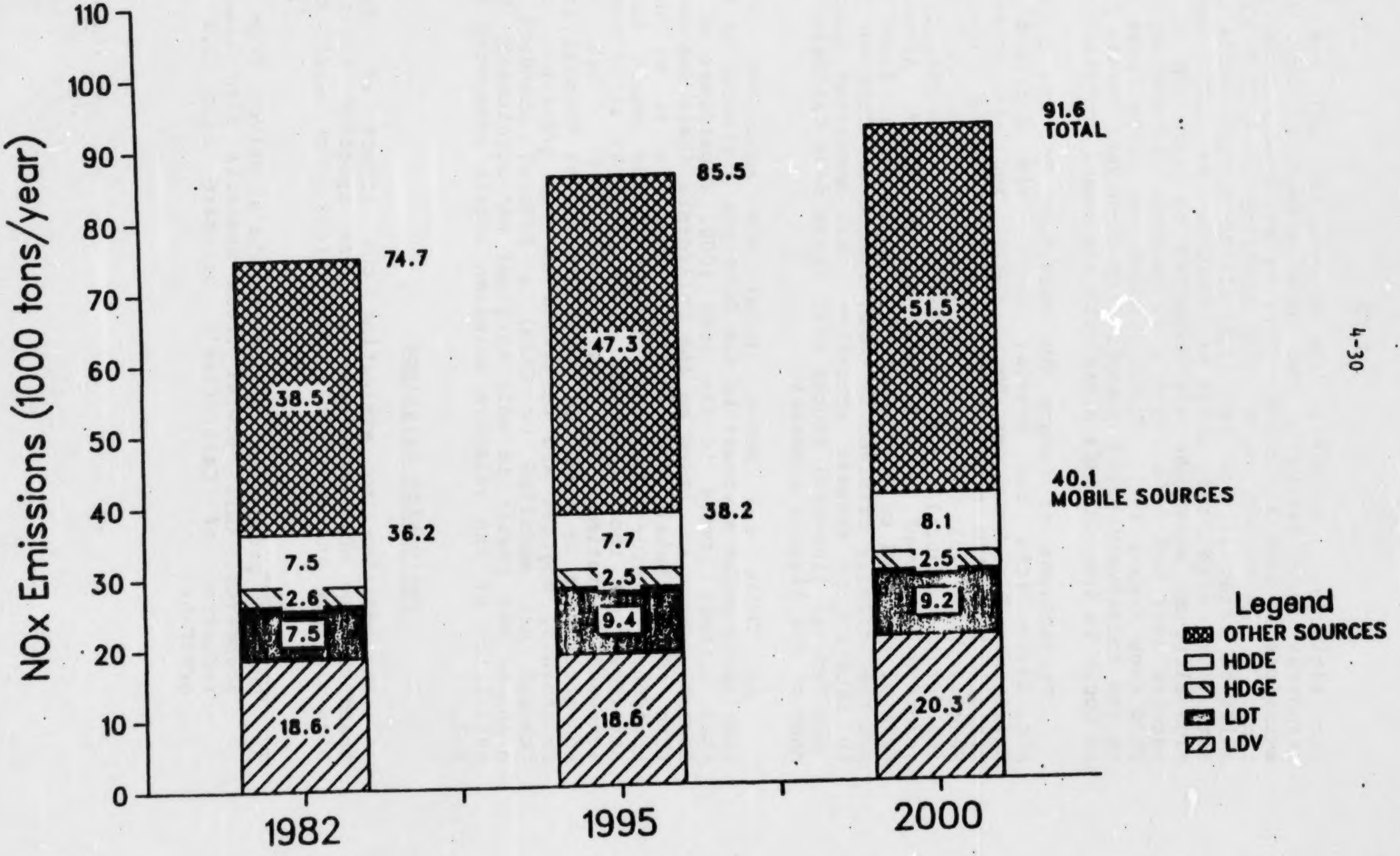

Table 4-3

South Coast Air Basin (SCAB)
NOx Projections (tons/day)

Source	1983	2000 Federal HDE Std. Scenarios			
		10.7	6.0	6.0/5.0*	6.0/4.0
LDV	327.9	227.2	227.2	227.2	227.2
LDT	94.5	60.0	60.0	60.0	60.0
HDGV	44.2	36.1	36.1	36.1	36.1
HDDV	134.0	169.6	137.1	130.5	105.3
Off-Highway	113.0	146.5	146.5	146.5	146.5
Stat. Point	200.7	205.6	205.6	205.6	205.6
Stat. Area	98.9	101.3	101.3	101.3	101.3
Total**	1013.2	946.3	913.8	907.2	882.0
Degree Above NAAQS Attainment Level (%)***	13	6	2	1	-1

---

* The 6.0/5.0 Federal scenario was not examined by CARB, but was estimated by EPA based on CARB's data; represents very marginal nonattainment of NAAQS.

** Totals are up to 2 percent greater than those provided by CARB, due to round-off error in recombining source categories.

*** The California SIP estimate is that NOx emission levels at or below approximately 895 tons per day are necessary for SCAB attainment of the NO_2 NAAQS. Based on this, the 6.0/4.0 Federal standard, which would be accompanied by a reduction of the California standard from 5.1 to 4.0, allows the SCAB to stay in attainment in 2000. (Initial attainment is projected for the late 1980's, regardless of Federal control.)

Source: California Air Resources Board, Mike Sheible, January 22, 1985, phone conversation.

nationwide NOx emissions was also determined. This larger scale analysis can be especially useful in evaluating the secondary effects of NOx control, such as acid rain formation. Because nationwide projections were not included in the NPRM, a brief explanation of the methodology used is in order.

Projections for the nation (48 continental states) are made using base-year inventories from the National Emissions Data System (NEDS).*[1] Motor vehicle inventories are adjusted for future VMT growth and emission control using nationwide average VMT growth rates from the MOBILE3 Fuel Consumption Model (shown in Table A-7) and MOBILE3 emission factor ratios for the various standard scenarios. Current emissions from other sources are adjusted using assumptions also shown in Table A-7.[21,28] In this nationwide analysis, stationary point sources are included due to the larger scale regional concerns usually associated with secondary NOx effects.

These nationwide NOx projections are shown in Table 4-4 and in Figures 4-5 and 4-6; these "base" and "controlled" cases refer to the same standards scenarios described earlier. As shown, without further LDT and HDE control, total nationwide NOx emissions are projected to grow by 13 percent between 1982 and 1995, with a 23 percent increase by the year 2000. However, with the final LDT and HDE standards in place, growth during the same periods is estimated to be 6 and 14 percent, respectively, or an overall reduction of 6-8 percent from future uncontrolled emissions.

3. Air Quality

Using the rollback model and input data described in the Draft RIA and Section II above, the effect of the final NOx standards on ambient NO_2 concentrations was evaluated for the eight low-altitude and two high-altitude urban areas mentioned earlier. Table 4-5 presents the results of this evaluation, comparing projected NO_2 NAAQS attainment status under both the promulgated standards and the baseline case. Because the rollback approach was used, the percent change in ambient NO_2 concentration tracks the change in NOx emissions (excluding point sources), which have already been described above.

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* Because the NEDS weaknesses exist primarily in the apportionment of VMT to individual counties and do not apply to statewide totals, the methodologies used to calculate nationwide NOx inventories are appropriate for use in this part of the analysis.

Table 4-4

Total Nationwide NOx Emissions
(1000 tons/year)

		1995		2000	
Source	1982	Base	Controlled	Base	Controlled
LDV	3,082	2,204	2,204(0%)*	2,422	2,422(0%)*
LDT	1,134	1,249	1,038(17%)	1,302	989(24%)
HDGV	466	415	368(11%)	420	357(15%)
HDDV	2,256	3,296	1,903(42%)	3,699	1,925(48%)
On-Highway Vehicles (subtotal)	6,938	7,164	5,513(23%)	7,843	5,693(27%)
Stationary Area	241	241	241(0%)	241	241(0%)
Combustion	3,013	3,342	3,342(0%)	3,478	3,478(0%)
Off-Highway	1,941	2,677	2,677(0%)	3029	3,029(0%)
Stationary Point	10,847	12,583	12,583(0%)	13,776	13,776(0%)
Total	22,981	26,007	24,356(6%)	28,367	26,217(8%)

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* Figures in parentheses indicate reductions from base case.

Figure 4-5

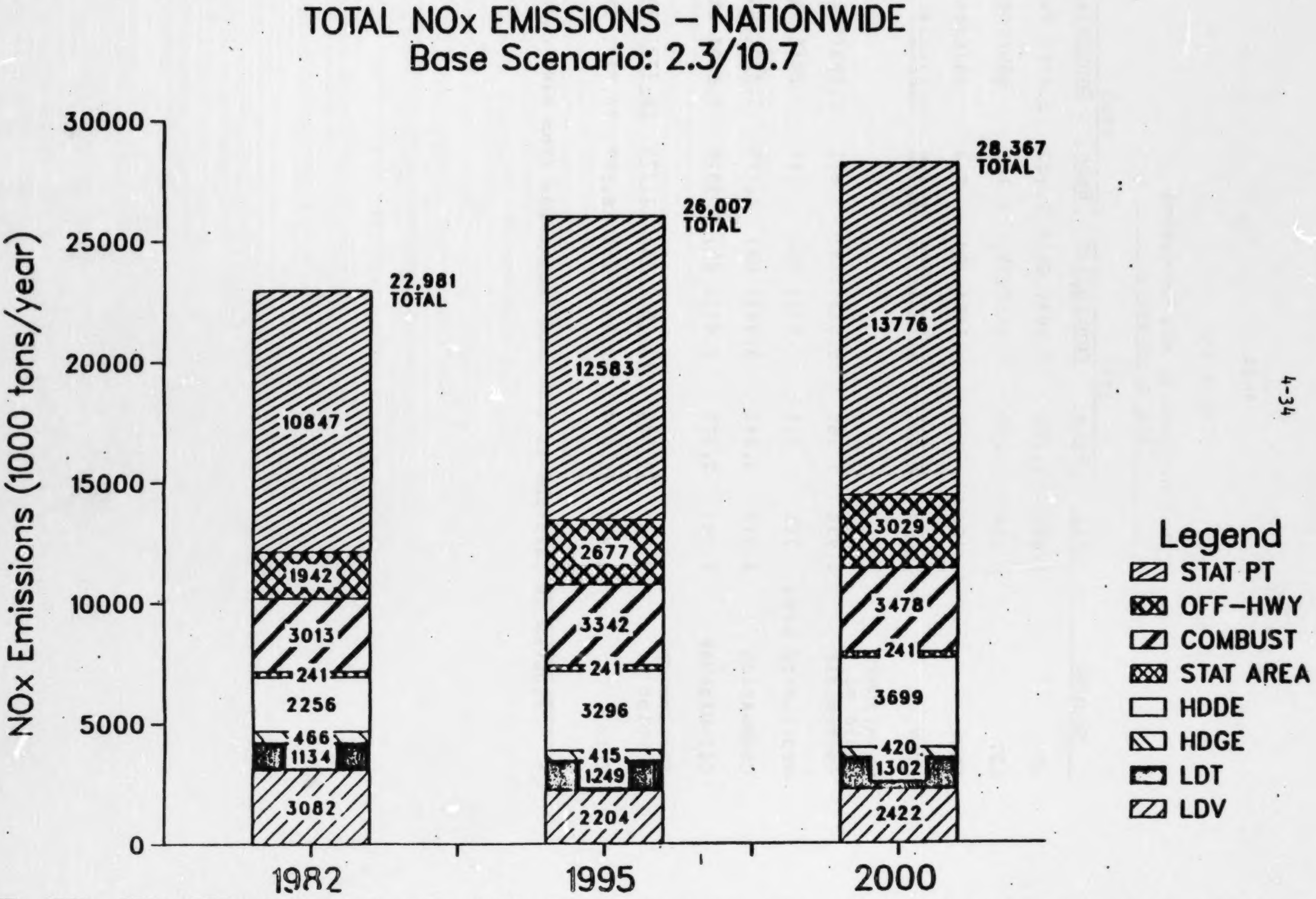
TOTAL NOx EMISSIONS – NATIONWIDE
Base Scenario: 2.3/10.7
NOx Emissions (1000 tons/year)
30000
25000
20000
15000
10000
5000
0
1982
1995
2000
22,981 TOTAL
26,007 TOTAL
28,367 TOTAL
10847
1942
3013
241
2256
466
1134
3082
12583
2677
3342
241
3296
415
1249
2204
13776
3029
3478
241
3699
420
1302
2422
Legend
▨ STAT PT
▩ OFF–HWY
▨ COMBUST
▩ STAT AREA
☐ HDDE
▧ HDGE
■ LDT
▨ LDV

Figure 4-6

TOTAL NOx EMISSIONS – NATIONWIDE
Controlled Scenario: 1.2/1.7; 6.0/5.0

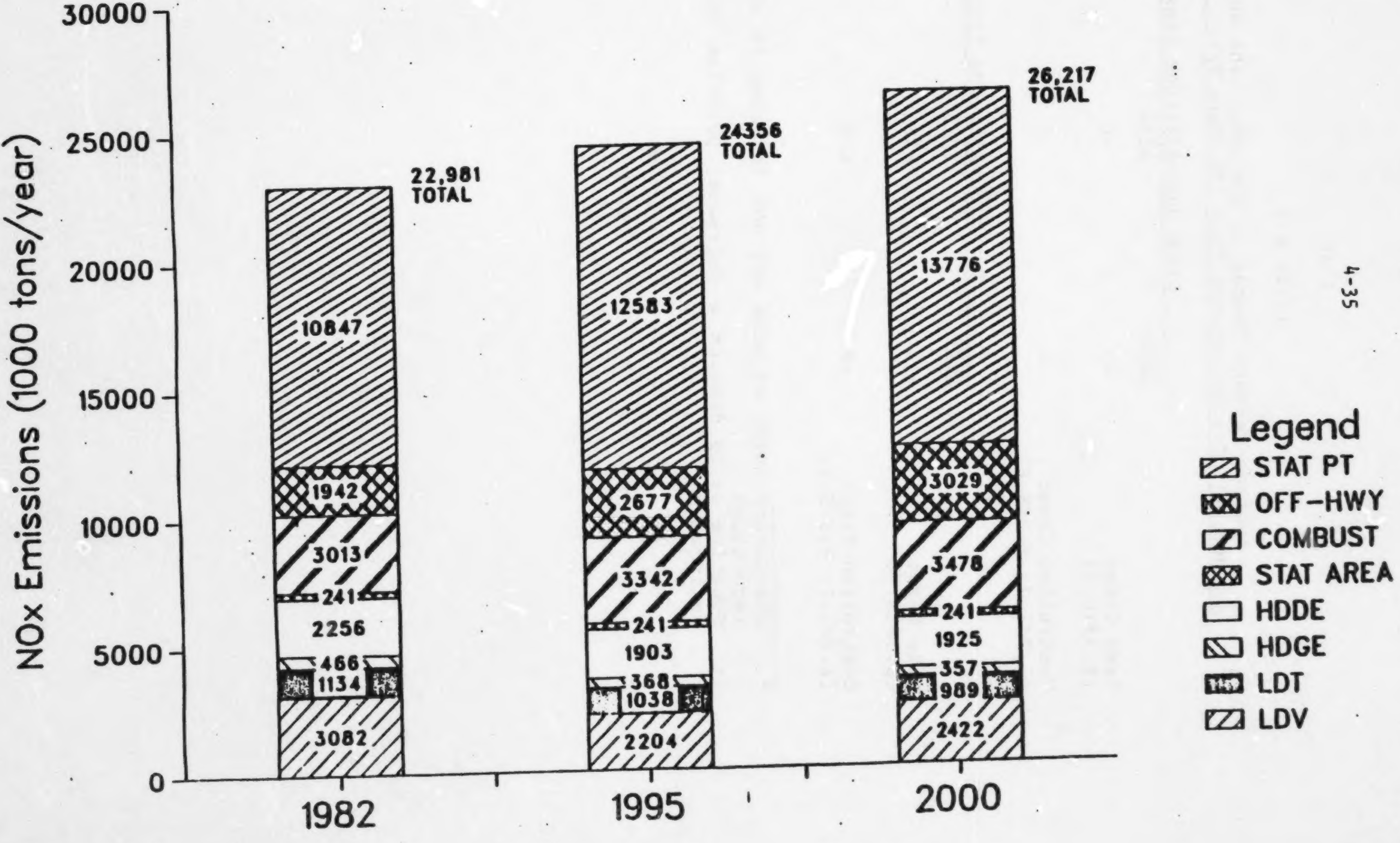

Table 4-5

Average Percent Change in NOx Emissions and Ambient NO_2 Concentrations from the Base Year (1982)*

	Eight Low-Altitude Areas**		
	1990	1995	2000
Base Case: (2.3/10.7)	-1	+6	+16
Controlled Case: (1.2/1.7; 6.0/5.0)	-6	-5	+1
	Two High-Altitude Areas**		
	1990	1995	2000
Base Case: (2.3/10.7)	+13	+26	+39
Controlled Case: (1.2/1.7; 6.0/5.0)	+9	+15	+24

---

* Stationary point sources are not included in the emission reductions.

** Negative value denotes a decrease; positive value denotes an increase.

Table 4-6 estimates the number of Standard Metropolitan Statistical Areas (SMSAs), or urban areas, projected to be above the ambient NO_2 standard of 0.053 ppm in several projection years. It should be noted that actual number of non-attainment areas shown is not to be taken as absolute, as projections of this type are difficult to make. Rather, the relative number of exceedances is more appropriate as a means of evaluating the relative impact of a particular control scenario. As shown, two of the three non-California areas fall into attainment with the final standards in place, with the three California cities predicted to be in only marginal non-attainment in the year 2000.

4. Conclusions

It is against the background of the above projections that EPA must evaluate the comments by manufacturers that there is insufficient need for NOx control to justify the proposed standards for light-duty trucks and heavy-duty engines. Even with the revised input data that project lower future emissions, overall growth in future NOx is still projected to be significant for both the nation as a whole and for the urban areas of concern. The same basic need for further NOx control demonstrated in the proposal still exists, and current action is necessary if future problems are to be dealt with effectively.

The statutory provisions of Section 202(a)(3)(E) allowing EPA to relax the NOx standards based upon air quality considerations place a positive burden on the Agency to substantiate a lack of need for more stringent levels. Based upon its projections of future emissions and their relationship to both the attainment of the National Ambient Air Quality Standard and to other actual or potential secondary impacts, EPA finds it impossible to make such a statement at this time. Therefore, the standards promulgated in the final rule have been developed under the provisions of Section 202(a)(3)(B)-(D), which provide for setting standards based upon those levels which do not increase cost or decrease fuel economy to an excessive and unreasonable degree.

B. Diesel Particulate Analysis

Revised projections of diesel particulate emissions and related impacts are presented in the following paragraphs. The analysis begins with urban emissions projections both with and without the promulgated HDE control, followed by a discussion of the impact of these diesel particulate emissions on urban air quality. The final section deals with the health and welfare impacts of diesel particulate exposure, including both non-cancer and carcinogenic health effects, visibility

Table 4-6

Number of SMSAs Projected to Exceed the NO_2 Ambient Air Quality Standard

	1984	1990	1995	2000
Base Case: (2.3/10.7)				
Low Altitude	0	0	1	1
High Altitude	0	1	2	2
California	1*	0	0	3
Total	1	1	3	6
Controlled Case: (1.2/1.7; 6.0/5.0)				
Low Altitude	0	0	0	0
High Altitude	0	1	1	1
California	1*	0	0	3
Total	1	1	1	4

---

* Los Angeles is the only SMSA currently in non-attainment of the NO_2 NAAQS.

reduction, and soiling. Unless specified, the analyses presented below utilize the methodology outlined in the Draft RIA, as modified in Section II above.

1. Urban Emissions

Unlike NOx, diesel particulate is modelled for urban areas across the nation in aggregate, without focus on particular cities. This is done because violation of the NAAQS for particulate is more widespread than it is for NOx. The final diesel particulate emissions projections are presented in Table 4-7. The two future scenarios shown differ only in the HDDV standards assumed; for light-duty diesels, the standards that are currently set to come into effect with the 1987 model year -- 0.20 and 0.26 g/mi for LDDVs and LDDTs, respectively -- are assumed. The "base" scenario represents no further control of HDDV particulate emissions, assuming uncontrolled emissions at 0.70 grams per brake-horsepower-hour (g/BHP-hr). The "controlled" case is based on the HDDV standards being promulgated in this rulemaking -- 0.60 in 1988, followed by 0.25 in 1991 and 0.10 g/BHP-hr in 1994. (Urban diesel buses will be subject to the 0.10 g/BHP-hr standard in 1991.)

As Table 4-7 indicates, urban diesel particulate emissions are projected to grow to twice the current levels by the year 2000 if no further HDDV controls are imposed (shown graphically in Figure 4-7). It is this HDDV category that makes up the majority of the total emissions, representing 84 percent in 1984 and 63 percent of the total in 2000. (This decrease in heavy-duty share occurs as the diesel penetration of the light-duty market increases.) Table 4-7 also includes a breakdown by class of the HDDV emissions, which shows that line-haul (Class VIIIB) diesels make up almost half of total HDDV emissions in 2000.

The effect of HDDV and urban bus control is significant, with the combined 1988/91/94 standards bringing about an estimated 46 percent decrease from the base (uncontrolled) case in the year 2000. This level of control essentially prevents significant growth beyond current levels, with about an 11 percent increase projected between 1984 and 2000 (see Figure 4-8).

The more stringent control (0.10 g/BHP-hr standard) of urban buses, beginning with 1991 models, and of other heavy-duty classes in 1994 is a substantial portion of this overall impact on emissions by the year 2000. The 0.10 g/BHP-hr standard accounts for 23 percent of the reduction in emissions from uncontrolled levels. From another perspective, if the 1994 0.10 standard were not implemented and the 0.25 standard simply continued on through 2000 for both buses and

Table 4-7

Base-year and Future Urban Diesel Particulate Emissions (tons/year)*

Vehicle Classes	1984 Levels	1995 HDDV Scenarios Base (0.70)	1995 HDDV Scenarios Controlled (0.60/.25/.10)	2000 HDDV Scenarios Base (0.70)	2000 HDDV Scenarios Controlled (0.60/.25/.10)
LDDV	5,699 (11%)**	13,392 (15%)	13,392 (23%)	19,700 (18%)	19,700 (33%)
LDDT	2,492 (5%)	13,072 (15%)	13,072 (23%)	20,713 (19%)	20,713 (35%)
HDDV	45,018 (84%)	61,485 (70%)	30,767 (54%)	68,528 (63%)	18,903 (32%)
Total	53,209(100%)	87,949(100%)	57,231(100%)	108,941(100%)	59,316(100%)

Breakdown of HDDV Emissions (tons/year)*

Vehicle Classes	1984 Levels	1995 HDDV Scenarios Base (0.70)	1995 HDDV Scenarios Controlled (0.60/.25/.10)	2000 HDDV Scenarios Base (0.70)	2000 HDDV Scenarios Controlled (0.60/.25/.10)
2B-8A	15,427(34%)**	24,062(39%)	12,355(40%)	27,343(40%)	7,541(40%)
8B	21,811(49%)	26,710(44%)	13,790(45%)	28,909(42%)	8,146(43%)
Buses	7,780(17%)	10,713(17%)	4,622(15%)	12,276(18%)	3,216(17%)
Total	45,018(100%)	61,485(100%)	30,767(100%)	68,528(100%)	18,903(100%)

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* "Best estimate" diesel sales fractions, shown in Table A-5, are assumed.

** Figures in parentheses indicate percent of total.

Figure 4-7

Urban Diesel Particulate Emissions
Base Scenario

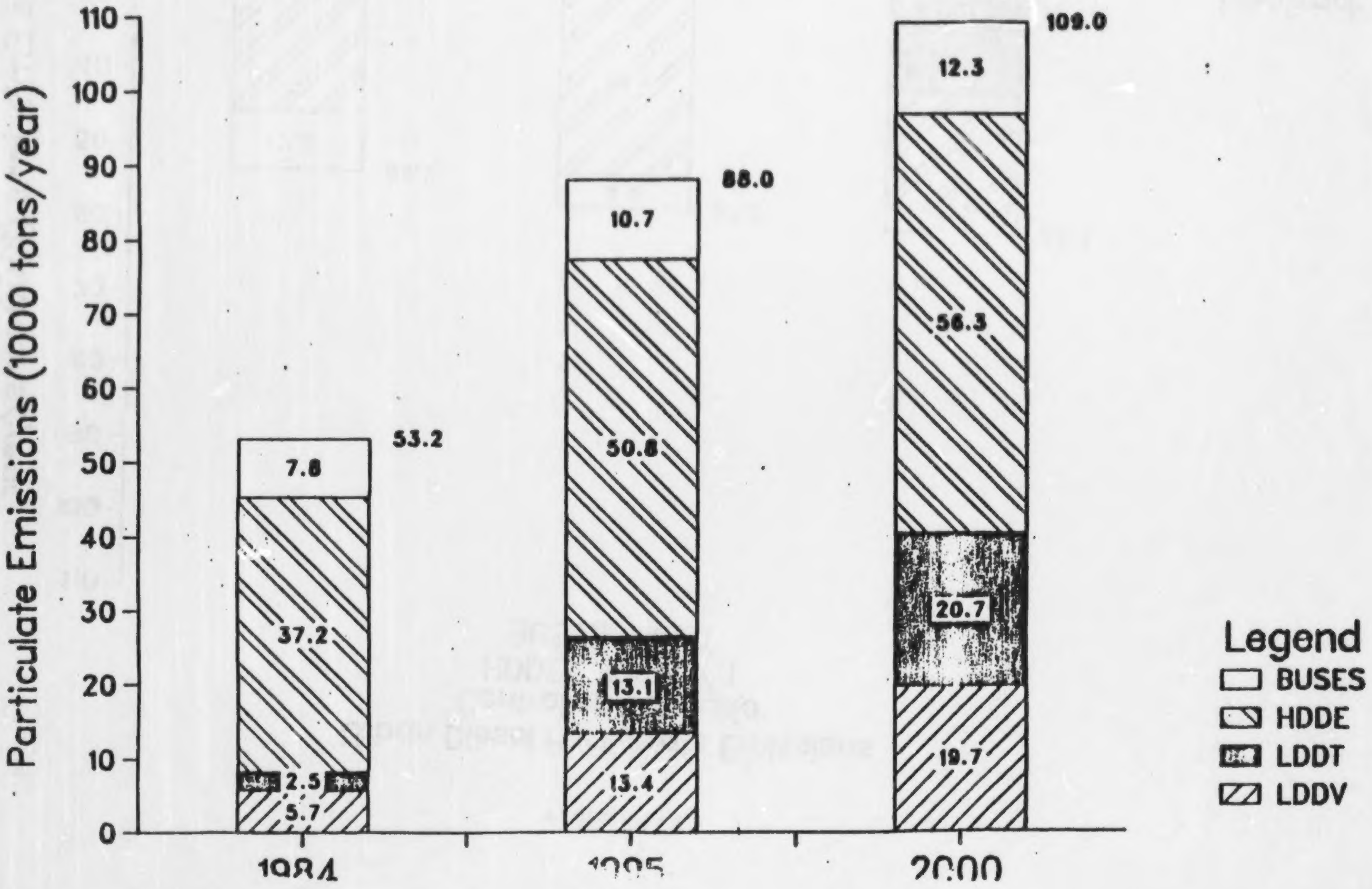
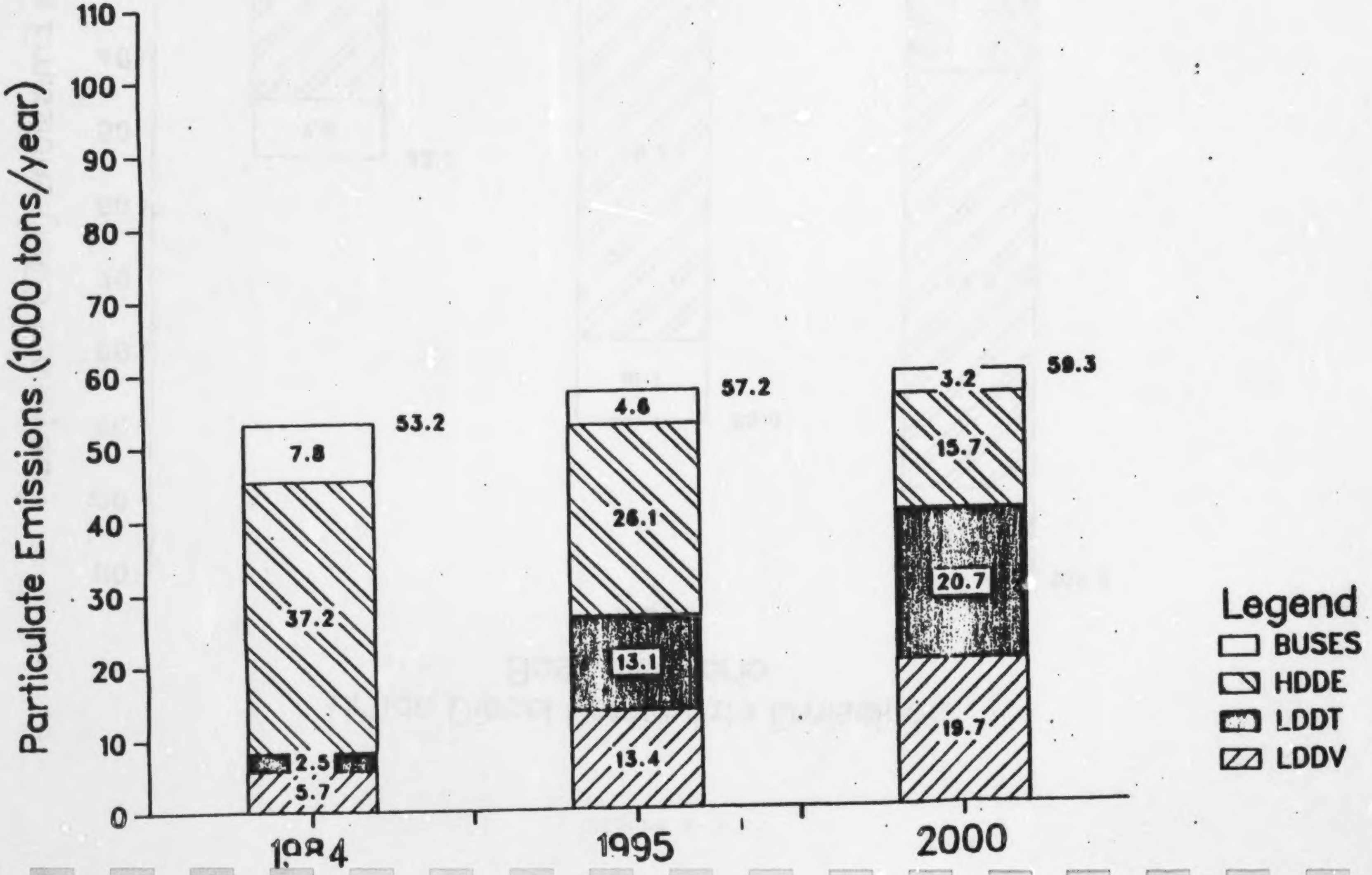


Figure 4-8

Urban Diesel Particulate Emissions
Controlled Scenario
HDDE: .6/.25/.1
BUSES: .6/.1



trucks, total diesel particulate emissions in the year 2000 would be approximately 33 percent higher than in 1982; however, with the final more stringent standards, growth during this period is constrained to an estimated 11 percent.

The emissions projections presented in Table 4-7 are based upon EPA's best estimates for the various input parameters; however, because of the difficulty in projecting future diesel penetration into the light-duty markets, a sensitivity analysis was performed. Instead of assuming that light-duty diesel production will continue to grow through 1995 (as in the "Best Estimate" analysis), another case was examined wherein 1990 levels of 5 percent and 15 percent diesel penetration of the LDV and LDT markets, respectively, was assumed to continue through the year 2000. (Best estimates of heavy-duty diesel penetration -- less difficult to predict -- were used in both cases.) Results of the sensitivity analysis are presented in Table 4-8.

As indicated, the use of the lower future diesel penetrations results in a 29-30 percent decrease in light-duty emissions in 1995 and a 47-50 percent decrease in the year 2000, in comparison to best estimate projections for the same two years. With respect to total diesel particulate emissions under the "Low Penetration" scenario, assuming no further control, growth between 1984 and 2000 would still be significant at 68 percent (compared to 105 percent assuming "Best Estimate Penetration"). With imposition of the 1988/91/94 standards on HDDVs, assuming low diesel penetration, year 2000 emissions would be approximately 25 percent lower than current levels (compared to the 11 percent increase over current levels projected using best estimates of light-duty diesel penetration).

2. Air Quality

The impact of growth in diesel particulate emissions on urban air quality is significant, as shown in Table 4-9. Current ambient diesel particulate concentrations in large cities are projected to grow from an average of 1-3 ug/m^3 to levels of 3-7 ug/m^3 by the year 2000 with no further control on HDDVs (using best estimate assumptions). With the standards promulgated in the final rule, diesel particulate concentrations in large cities will be reduced to 1.5-4 ug/m^3 (best estimates), a reduction to almost half of baseline concentrations.

3. Health and Welfare Effects

As discussed in the Draft RIA and the DPS,[5] exposure to diesel particulate emissions has an impact on these four

Table 4-8

Sensitivity Analysis of Light-Duty Diesel Penetration

Urban Diesel Particulate Emissions (1000 tons/year)*

Vehicle Class	1984 Levels	1995 Best Estimate	1995 Low Growth	2000 Best Estimate	2000 Low Growth
LDDV	5.7	13.4	9.4	19.7	9.9
LDDT	2.5	13.1	9.3	20.7	11.0
HDDV**	45.0	61.5	61.5	68.6	68.6
TOTAL	53.2	88.0	80.2	109.0	89.5

---

* Standards scenario: no further HDDV control (0.7 g/BHP-hr). LDDV and LDDT emissions do not change with heavy-duty control scenario.

** HDDV class includes buses.

Table 4-9

Effect of Diesel Particulate Control on Urban Air Quality*

	Total Diesel Particulate Concentration (ug/m^3)				
		1995**		2000**	
	1984	Base	Controlled	Base	Controlled
Ambient Urban Concentrations* **					
City Population:					
Greater than 1,000,000	1.3-3.0	2.3-5.5	1.5-3.6	2.9-6.8	1.6-3.7
500,000 - 1,000,000	0.8-2.0	1.5-3.6	1.0-2.4	2.0-4.6	1.1-2.5
250,000 - 500,000	1.0-1.6	1.8-3.0	1.2-2.0	2.2-3.7	1.2-2.0
100,000 - 250,000	0.7-1.7	1.2-3.2	0.8-2.1	1.5-4.0	0.8-2.2
Annual Average Exposure to U.S. Urban Dwellers					
TOTAL	2.4	4.4	2.9	5.5	3.0
Microscale Concentrations					
Roadway Tunnel:					
Typical	63	91	60	105	57
Severe	159	231	152	266	145
Street Canyon:					
Typical	2	3	2	4	2
Severe	16	23	15	26	14
On Expressway:					
Typical	7	11	7	11	6
Severe	28	41	27	48	26
Beside Expressway	6	9	6	9	5

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* Based on best-estimate projections.
** Control effectiveness is approximately 35% in 1995 and 46% in 2000.
*** Ranges are average values plus and minus one standard deviation.

areas: 1) non-cancer health effects, 2) carcinogenic health effects, 3) visibility, and 4) soiling.

a. Non-Cancer Health Effects

Particulate matter in general has long been regarded as hazardous to human health. EPA recognized this danger and established an NAAQS for total suspended particulate (TSP) as early as 1971. As discussed in Section II, EPA has proposed an ambient standard that will focus on inhalable particles (i.e., those with diameters of 10 microns or less (PM_{10})), because it is this fraction that appears to be responsible for most of the human health effects associated with TSP.

As mentioned earlier, diesel particulates fall easily into the PM_{10} category, as the majority are classified as fine particulate (less than 2.5 microns in diameter). Although a large body of data has been developed regarding the health effects of inhalable particulate matter, research limited specifically to diesel particulate is relatively new and somewhat inconclusive. An analysis of the available data indicates that, until more is known, diesel particulate generally should be regarded as being equivalent to other forms of inhalable particulate matter in terms of the hazard it presents to human health, although there is a possibility it may be somewhat more hazardous.[5] It should be pointed out, however, that even if regarded as posing the same hazard, diesel particulate is emitted directly into the breathing zone, rather than from tall stacks that would promote dispersion. Thus, the potential for human exposure is maximized.

Two basic concerns exist with respect to the health risk posed by inhalable particulate in general. First, inhalable particulates are small enough so that they are not as readily prevented by the natural body defenses from reaching the lower respiratory tract, as would coarser particles. Fine particulate matter can penetrate to the alveoli, or deepest recesses of the lungs, where the oxygen/carbon dioxide exchange takes place with the circulatory system.[29] The body requires months or years to clear foreign matter from the alveolar region, as opposed to hours or days to clear the upper respiratory system. The second concern is that inhalable particulate may be composed of toxic materials or may have hazardous materials adsorbed onto its surface.

The most obvious non-cancer health effect of an inhalable particulate, such as that produced by diesels, is injury to the surfaces of the respiratory system, which could result in reduced lung function, bronchitis or chronic respiratory symptoms. The hazardous chemicals that may be associated with particulate matter (e.g., organic compounds, lead, antimony, etc.) can either react with lung tissue or be transported to other parts of the body by the circulatory system. Particulate matter may also weaken the resistance of the body to infection and there are indications that it reacts adversely in conjunction with other atmospheric pollutants. For example, studies in London, New York, Buffalo, and Nashville have found an increase in the mortality rate, especially among older persons, when high particulate levels were accompanied by high sulfur dioxide levels.[30]

From the above discussion, it is clear that inhalable particulate matter (PM_{10}) has been linked directly with a myriad of adverse non-cancer health effects, and it is based on this information that EPA has proposed the NAAQS for PM_{10}. Also, diesel particles are all inhalable particulate and, therefore, can potentially represent the same concern. This relationship can be used to assess the overall benefits of controlling HDDV diesel particulate.

As stated in the Draft RIA for the PM_{10} NAAQS, 105-329 counties are projected to be in non-attainment of the range of primary PM_{10} standards being considered for 1989.[26] Even after reasonable non-mobile source emission controls are implemented, numerous violations of the NAAQS are still projected to occur. As shown in Table 4-9, if no further HDDV controls were implemented, annual average exposure to diesel particulate for urban dwellers would be at a level of approximately 5.5 ug/m^3 in the year 2000, or about 10 percent of the suggested PM_{10} NAAQS. Promulgation of the HDDV standards is projected to reduce this exposure to about 3.0 ug/m^3, therefore playing an important role in reducing urban PM_{10} exposure. Furthermore, the resulting reduction in diesel particulate emissions within urban areas that continue to violate the suggested PM_{10} NAAQS will directly reduce the non-cancer health effects associated with inhalable particulates in general.

b. Carcinogenic Health Effects

A number of studies have concluded that exposure to diesel particulate probably poses an additional risk of acquiring lung cancer. EPA surveyed these studies and developed scenario-specific risk factors for lung cancer incidence, taking into account the relative reduction of compounds producing the cancer-risk with respect to reductions in total diesel particulate.[5] Table 4-10 shows the resultant cancer risk estimates associated with diesel particulate for both the base-case and the controlled-case scenarios along with estimated risks from other known carcinogens, shown for purposes of comparison.

Table 4-10

Comparison of Risks from Various Sources

Sources of Risk	Estimated Annual Risk (risk/person-year)	Exposed Population
Commonplace Risks of Death		
Motor Vehicle Accident	222.0×10^{-6}	Entire U.S.
Drowning	26.0×10^{-6}	Entire U.S.
Burns	21.0×10^{-6}	Entire U.S.
Tornados, Floods, Lightning, Hurricanes, etc.	2.0×10^{-6}	Entire U.S.
Risks of Cancer Incidence		
Diesel Particulate (1995):		Urban U.S.
Base Scenario	$1.2 \times 10^{-6} - 6.2 \times 10^{-6}$	
Controlled Scenario	$0.8 \times 10^{-6} - 4.1 \times 10^{-6}$	
Diesel Particulate (2000):		Urban U.S
Base Scenario	$1.5 \times 10^{-6} - 7.7 \times 10^{-6}$	
Controlled Scenario	$0.8 \times 10^{-6} - 4.2 \times 10^{-6}$	
Natural Background Radiation (sea level)	20.0×10^{-6}	Entire U.S.
Average Diagnostic Medical X-Rays in the U.S.	20.0×10^{-6}	Widespread
Frequent Airline Passenger (4 hours per week flying)	10.0×10^{-6}	Limited
Four Tablespoons Peanut Butter Per Day (due to presence of aflatoxin)	8.0×10^{-6}	Fairly Widespread
Ethylene Dibromide	4.2×10^{-6}	Widespread
One 12-Ounce Diet Drink Per Day	2.6×10^{-6}	Widespread
Arsenic	1.7×10^{-6}	1% of U.S.
Miami or New Orleans Drinking Water (due to presence of chloroform)	1.0×10^{-6}	Southern U.S., Urban
Lung Cancers:		Entire U.S.
For Smokers Due to Smoking	419.0×10^{-6}	
For General Population Due to Causes Other Than Smoking	73.9×10^{-6}	

The data indicate that while the risk of contracting lung cancer is greatest from smoking, exposure to diesel particulate may represent a significant portion of all non-smoking-related lung cancer. The upper limit of the uncontrolled (base) scenario in 2000 would represent almost eight individuals in a million, or 10 percent of all non-smoking-related lung cancer in the U.S. The lower limit still represents over one in a million individuals, which has been used in the past by regulatory agencies as a cut-off point for determining the need for control. Thus, as indicated in the NPRM, Table 4-10 shows that a relatively small but significant cancer risk may be attributable to diesel particulate exposures. The promulgated HDDV controls are estimated to reduce this risk by almost one-half in the year 2000.

c. Visibility Effects

Reduced visibility is one of the more readily apparent effects of diesel particulate. Because diesel particles are of a diameter most effective in scattering light and their 65-80 percent carbon content produces a high degree of light absorption, visibility reduction results.

Table 4-11 presents the estimated visibility impacts of the base- and controlled-case scenarios in terms of the average percent reduction due to diesel particulates in 1995 and 2000 urban visibility from early 1970's levels. As shown, in the absence of controls, increases in diesel particulate levels will result in reduced visibility, ranging from a 22 percent reduction in largest cities, to 4-9 percent decreases for less populous urban areas in the year 2000. HDDV control is projected to cut these visibility reductions to 12 percent in the largest cities, and to 2-5 percent in smaller urban areas. The controlled-case scenario thus offers a 2-10 percent improvement in visibility over the base-case scenario, depending on the size of the city. The lower limit of this impact (i.e., the effect for smaller cities), may not be perceptible. However, the effect for large cities would show a noticeable improvement in visibility. The promulgated standards, therefore, will provide an overall benefit that would be most apparent in the areas where it was most needed.

d. Soiling Effects

In a review of the scientific literature, the DPS[5] found some evidence suggesting that because of its black color and oily nature, diesel particulate may have a disproportionate effect on soiling compared to the effect of other types of particulate (i.e., diesel particulate would produce more soiling than TSP on a gram-for-gram basis). The black color may make the soiling more apparent to the observer and the oily

Table 4-11

Average Reduction in Visibility
Due to Diesel Particulate
(percent reductions from base-year visibility)

City Size (population)	1995 Base	1995 Controlled	2000 Base	2000 Controlled
More than 1,000,000	18	12	22	12
500,000-1,000,000	7	5	9	5
250,000-500,000	5	3	7	4
100,000-250,000	3	2	4	2

nature may make it more difficult to clean. The net effect would be to increase costs to the general public for more frequent and more thorough cleaning events. However, because of the paucity of scientific data on the physical soiling effects of diesel particulate and TSP, no definitive statement of these relationships can be made at this time.

There is a somewhat larger body of literature available regarding the costs associated with various levels of soiling. Summaries of this economic literature can be found in an EPA report regarding the benefits associated with diesel particulate control,[31] and in the Draft RIA. These reports conclude that there are significant economic benefits to be gained from control of diesel particulates with respect to soiling.

4. Conclusions

Based on the above projections, EPA believes that diesel particulate emissions are a serious environmental concern with respect to their impact on various health and welfare aspects. It seems apparent that significant reductions in heavy-duty diesel emissions are an essential element in dealing with this environmental problem. The stringent controls on heavy-duty diesels and urban buses being promulgated in the final rule are viewed as effective means of reducing the future growth in particulate emissions.

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A

APPENDIX

(Input Information: Tables A-1 through A-10)

B

Table A-1

U.S. Urban VMT* (billions of miles/year)

Source	Years 1982	 1984	 1995	 2000
LDV	604.15	629.25	775.36	841.77
-Gas	590.65	614.71	722.19	759.43
-Diesel	13.50	14.54	53.17	82.34
LDT	169.82	179.52	225.43	246.36
-Gas	166.23	172.90	181.73	177.25
-Diesel	3.59	6.62	43.70	69.11
HDGV	35.76	35.80	37.44	39.64
HDDV	16.55	18.28	30.48	35.11
Buses	3.57	3.76	5.03	5.75
-Gas	1.22	1.23	1.37	1.50
-Diesel	2.35	2.53	3.66	4.25
Total	829.85	866.61	1073.74	1168.63

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* Based on MOBILE3 Fuel Consumption Model, January 21, 1985.

C

Table A-2

Urban Fraction of VMT - HDDV*

Model Year	2B	3-5	6	7	8A	8B
2000	0.633	0.633	0.473	0.396	0.394	0.176
1999	0.633	0.633	0.473	0.396	0.394	0.176
1998	0.633	0.633	0.473	0.396	0.394	0.176
1997	0.633	0.633	0.473	0.396	0.394	0.176
1996	0.633	0.633	0.470	0.395	0.388	0.176
1995	0.633	0.633	0.466	0.394	0.382	0.176
1994	0.633	0.633	0.463	0.394	0.377	0.176
1993	0.633	0.633	0.459	0.393	0.372	0.176
1992	0.633	0.633	0.456	0.392	0.366	0.176
1991	0.633	0.633	0.455	0.391	0.365	0.176
1990	0.633	0.633	0.454	0.390	0.363	0.176
1989	0.633	0.633	0.454	0.389	0.362	0.176
1988	0.633	0.633	0.453	0.388	0.360	0.176
1987	0.633	0.633	0.452	0.387	0.359	0.176
1986	0.633	0.633	0.451	0.387	0.359	0.176
1985	0.633	0.633	0.450	0.386	0.359	0.176
1984	0.633	0.633	0.449	0.386	0.359	0.176
1983	0.633	0.633	0.448	0.385	0.359	0.176
1982	0.633	0.633	0.447	0.385	0.359	0.176
1981	0.632	0.632	0.443	0.383	0.359	0.176
1980	0.632	0.632	0.439	0.382	0.359	0.176
1979	0.631	0.631	0.436	0.380	0.358	0.176
1978	0.631	0.631	0.432	0.379	0.358	0.176
1977	0.630	0.630	0.428	0.377	0.358	0.176
1976	0.630	0.590	0.430	0.370	0.300	0.176
1975	0.630	0.550	0.430	0.350	0.241	0.176
1974	0.630	0.550	0.430	0.340	0.241	0.176
1973	0.630	0.550	0.420	0.340	0.241	0.176
1972	0.630	0.550	0.420	0.330	0.241	0.176
1971	0.630	0.550	0.420	0.330	0.241	0.176
1970	0.630	0.550	0.420	0.330	0.241	0.176
1969	0.630	0.550	0.420	0.330	0.250	0.176
1968	0.630	0.550	0.420	0.340	0.259	0.176
1967	0.630	0.550	0.420	0.340	0.268	0.176
1966	0.630	0.550	0.420	0.340	0.268	0.176
1965	0.630	0.550	0.420	0.350	0.268	0.176

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* Used in MOBILE3 Fuel Consumption Model to convert nationwide VMT into urban VMT; based on MOBILE3 conversion factor analysis.

D

Table A-3

Urban Fraction of VMT - HDGV*

Model Year	2B	3-5	6	7	8
2000	0.710	0.710	0.829	0.775	0.850
1999	0.710	0.710	0.829	0.775	0.850
1998	0.710	0.710	0.829	0.775	0.850
1997	0.710	0.710	0.829	0.775	0.850
1996	0.709	0.709	0.819	0.767	0.850
1995	0.707	0.707	0.809	0.759	0.850
1994	0.706	0.706	0.799	0.751	0.850
1993	0.704	0.704	0.789	0.743	0.850
1992	0.703	0.703	0.779	0.735	0.850
1991	0.702	0.702	0.772	0.733	0.850
1990	0.701	0.701	0.765	0.730	0.850
1989	0.699	0.699	0.757	0.728	0.850
1988	0.698	0.698	0.750	0.725	0.850
1987	0.697	0.697	0.743	0.723	0.850
1986	0.695	0.695	0.732	0.715	0.826
1985	0.693	0.693	0.721	0.706	0.801
1984	0.691	0.691	0.709	0.698	0.777
1983	0.689	0.689	0.698	0.689	0.752
1982	0.687	0.687	0.687	0.681	0.728
1981	0.688	0.688	0.680	0.670	0.708
1980	0.689	0.689	0.674	0.660	0.689
1979	0.689	0.689	0.667	0.650	0.669
1978	0.690	0.690	0.660	0.640	0.650
1977	0.690	0.690	0.660	0.630	0.630
1976	0.690	0.685	0.660	0.630	0.580
1975	0.690	0.680	0.660	0.630	0.530
1974	0.690	0.680	0.660	0.630	0.560
1973	0.690	0.680	0.660	0.630	0.590
1972	0.690	0.680	0.660	0.630	0.620
1971	0.690	0.680	0.660	0.630	0.610
1970	0.690	0.680	0.660	0.630	0.600
1969	0.690	0.680	0.660	0.630	0.600
1968	0.690	0.680	0.660	0.630	0.590
1967	0.690	0.680	0.660	0.630	0.590
1966	0.690	0.680	0.660	0.630	0.590
1965	0.690	0.680	0.660	0.630	0.590

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* Used in MOBILE3 Fuel Consumption Model to convert nationwide VMT into urban VMT; based on MOBILE3 conversion factor analysis.

E

Table A-4

Light-Duty Diesel Sales Fractions

Model Year	"Best Estimate"		"Low Growth"*	
	LDV	LDT	LDV	LDT
2000	.115	.339	.050	.150
1999	.115	.339	.050	.150
1998	.115	.339	.050	.150
1997	.115	.339	.050	.150
1996	.115	.339	.050	.150
1995	.115	.339	.050	.150
1994	.102	.300	.050	.150
1993	.089	.263	.050	.150
1992	.076	.226	.050	.150
1991	.063	.188	.050	.150
1990	.050	.150	.050	.150
1989	.046	.130	.046	.130
1988	.041	.120	.041	.120
1987	.037	.110	.037	.110
1986	.032	.100	.032	.100
1985	.028	.090	.028	.090
1984	.023	.080	.023	.080
1983	.019	.077	.019	.077
1982	.039	.071	.039	.071
1981	.060	.056	.060	.056
1980	.045	.024	.045	.024
1979	.026	.013	.026	.013
1978	.009	.006	.009	.006
1977	.003	.001	.003	.001
1976	.003	.001	.003	.001
1975	.003	.001	.003	.001
1974	.003	.000	.003	.000
1973	.002	.000	.002	.000
1972	.002	.000	.002	.000
1971	.001	.000	.001	.000
1970	.000	.000	.000	.000
1969	.000	.000	.000	.000
1968	.000	.000	.000	.000
1967	.000	.000	.000	.000
1966	.000	.000	.000	.000
1965	.000	.000	.000	.000

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* "Low Growth" fractions used in diesel penetration sensitivity analysis.

F

Table A-5

Heavy-Duty Diesel Sales Fractions*

Model Year	Heavy-Duty Truck Class 2B	3-5	6	7	8A	8B
2000	.300	.300	.550	.700	1.000	1.000
1999	.300	.300	.550	.700	1.000	1.000
1998	.300	.300	.550	.700	1.000	1.000
1997	.300	.300	.550	.700	1.000	1.000
1996	.300	.300	.540	.690	.988	1.000
1995	.300	.300	.530	.680	.976	1.000
1994	.300	.300	.520	.670	.965	1.000
1993	.300	.300	.510	.660	.953	1.000
1992	.300	.300	.500	.650	.941	1.000
1991	.290	.290	.486	.640	.928	1.000
1990	.280	.280	.472	.630	.915	1.000
1989	.270	.270	.458	.620	.901	1.000
1988	.260	.260	.444	.610	.888	1.000
1987	.250	.250	.430	.600	.875	1.000
1986	.232	.232	.419	.596	.878	1.000
1985	.215	.215	.409	.592	.881	1.000
1984	.197	.197	.398	.588	.883	1.000
1983	.180	.180	.388	.584	.886	1.000
1982	.162	.162	.377	.580	.889	1.000
1981	.122	.122	.309	.589	.865	1.000
1980	.081	.081	.242	.598	.841	1.000
1979	.041	.041	.174	.606	.818	1.000
1978	.000	.000	.106	.615	.794	1.000
1977	.000	.000	.100	.578	.770	1.000
1976	.000	.003	.071	.514	.726	.960
1975	.000	.005	.041	.449	.634	.920
1974	.000	.004	.038	.415	.586	.920
1973	.000	.004	.034	.382	.540	.921
1972	.000	.003	.031	.348	.492	.921
1971	.000	.003	.054	.341	.482	.923
1970	.001	.003	.076	.333	.470	.925
1969	.002	.012	.082	.348	.492	.867
1968	.002	.022	.088	.364	.514	.809
1967	.003	.031	.094	.379	.535	.751
1966	.003	.029	.100	.413	.583	.721
1965	.002	.026	.105	.447	.632	.690

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* Based on MOBILE3 conversion factor analysis.

G

Table A-6

Fleet-Average Heavy-Duty
Emission Conversion Factors (BHP-hr/mi)*

Model Year	Gasoline	Diesel
1962	1.29	2.74
1963	1.31	2.74
1964	1.32	2.73
1965	1.33	2.72
1966	1.35	2.76
1967	1.36	2.82
1968	1.37	2.88
1969	1.37	2.94
1970	1.37	3.00
1971	1.37	3.08
1972	1.37	3.15
1973	1.34	3.19
1974	1.31	3.23
1975	1.28	3.27
1976	1.20	3.23
1977	1.12	3.19
1978	1.08	3.07
1979	1.05	2.95
1980	1.01	2.84
1981	0.98	2.72
1982	0.95	2.60
1983	0.95	2.56
1984	0.95	2.51
1985	0.96	2.47
1986	0.97	2.43
1987	0.97	2.38
1988	0.97	2.38
1989	0.96	2.37
1990	0.96	2.36
1991	0.96	2.35
1992	0.95	2.34
1993	0.94	2.33
1994	0.94	2.33
1995	0.93	2.32
1996	0.92	2.31
1997	0.92	2.31

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* Based on MOBILE3 conversion factor analysis.

H

Table A-7

Growth Rates and Assumptions Used in FRM NOx Analysis

VMT Growth Rates*
(%/year, compound)

Vehicle Class	1982-1995 Urban	1982-1995 Nationwide	1982-2000 Urban	1982-2000 Nationwide
LDV**	+1.9	+1.9	+1.9	+1.9
LDT**	+2.2	+2.2	+2.1	+2.1
HDGV	+0.4	0.0	+0.6	+0.2
HDDV	+4.7	+3.2	+4.2	+2.9

Stationary Source Assumptions

Source Category	Growth Rate (percent/year)	Discount Factor
Stationary Point***	+1.3	0.0
Off-Highway	+2.5	1.0
Combustion	+0.8	1.0
Stationary Area	0.0	1.0

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* Based on MOBILE3 Fuel Consumption Model, urban growth rates also used in diesel particulate analysis.

** Light-duty urban fractions of VMT are assumed to remain constant with model year; therefore, urban and nationwide growth rates are equal.

*** Stationary point source growth rate assumes a certain level of future NOx control, based on ICF, Inc., projections; point source emissions included only in nationwide NOx projections.

I

Table A-8

SMSAs Modelled for NO_2 (Design Values, ppm NO_2) [a]

NPRM Analysis [b] (1980)	Interim Analysis [c],[d] (1980-82)	FRM Analysis [c] (1981-83)
Boston (0.050)	Boston (0.036)	Chicago (0.044)
Chicago (0.060)	Chicago (0.052)	Cincinnati (0.036)
Cleveland (0.048)	Nashville (0.053)	Nashville (0.053)
Nashville (0.047)	New York (0.036)	New York (0.037)
Philadelphia (0.046)	Newark (0.045)	Newark (0.040)
Steubenville (0.040)	Philadelphia (0.039)	Philadelphia (0.040)
*Denver (0.046)	Seattle (0.048)	Pittsburgh (0.035)
*Reno (0.048)	Tucson (0.037)	Wash., D.C. (0.037)
	Wash., D.C. (0.036)	*Denver (0.052)
	*Denver (0.041)	*Reno (0.043)
	*Reno (0.043)	Los Angeles (0.059)
		Anaheim (0.045)
		Riverside (0.042)

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[a] California SMSAs included only in the FRM analysis; future projections based on CARB data.

[b] NO_2 concentrations at or above 0.040 ppm (75% of std.)

[c] NO_2 concentrations at or above 0.035 ppm (66% of std.)

[d] Interim analysis results presented in Motor Vehicle NOx Inventories (Technical Report), and letters to T. M. Fisher (GM) and Donald R. Buist (Ford), all contained in the Public Docket.

* High-altitude SMSAs.

J

Table A-9

Low Altitude NOx Emission Rates and Assumptions Different Than MOBILE3 Values for Emission Inventory and Air Quality Analysis

	Vehicle Type	Model Year	Emission Rate			Useful Life[4]
			ZM[1]	DR[2]	SEA[3]	
Base Case: (2.3/10.7)	LDGT	1987+	1.74	0.04	40%	Full
	LDDT	1978-80	1.83	0.06	--	Half
		1981-84	1.48	0.06	--	Half
		1985+	1.89	0.03	40%	Full
	HDGV	1987	4.86	0.10	--	Half
		1988	4.83	0.10	--	Full
		1989-90	4.79	0.10	40%	Full
		1991-93	4.71	0.09	40%	Full
		1994-96	4.58	0.09	40%	Full
		1997+	4.50	0.09	40%	Full
	HDDV	1987	17.58	0.00	--	Half
		1988	23.18	0.00	--	Full
		1989-90	23.06	0.00	40%	Full
		1991-93	22.84	0.00	40%	Full
		1994-96	22.60	0.00	40%	Full
		1997+	22.44	0.00	40%	Full
Controlled Case: (1.2/1.7; 6.0/5.0)	LDGT					
	Cl. II a[6]	1987	1.74	0.04	40%	Full
		1988+	1.21	0.04	40%	Full
	LDDT	1978-87		Same as Base Case		
	Cl. I[5]	1988+	0.94	0.03	40%	Full
	Cl. II a[6]	1988+	1.97	0.03	40%	Full
	HDGV	1987		Same as Base Case		
		1988	4.61	0.10	--	Full
		1989-90	4.57	0.10	40%	Full
		1991-93	3.76	0.09	40%	Full
		1994-96	3.66	0.09	40%	Full
		1997+	3.59	0.09	40%	Full
	HDDV	1987		Same as Base Case		
		1988	13.05	0.05	40%	Full
		1989-90	12.98	0.05	40%	Full
		1991-93	10.73	0.05	40%	Full
		1994-96	10.62	0.05	40%	Full
		1997+	10.54	0.05	40%	Full

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[1] Zero-mile emissions (g/mi).
[2] Deterioration rate (g/mi-10K mi).
[3] Selective Enforcement Audit.
[4] Certification to half or full useful life.
[5] Less than 6,000 lbs GVW.
[6] 6,001 - 8,500 lbs GVW.

K

Table A-10

High-Altitude NOx Emission Rates and Assumptions Different than MOBILE3 Values for Emission Inventory and Air Quality Analysis

	Vehicle Type	Model Year	Emission Rate			Useful Life[4]
			ZM[1]	DR[2]	SEA[3]	
Base Case: (2.3/10.7)	LDGT		Same as Low Altitude			
	LDDT		Same as Low Altitude			
	HDGV	1987	3.84	0.10	40%	Half
		1988	3.81	0.10	--	Full
		1989-90	3.78	0.10	40%	Full
		1991-93	3.72	0.09	40%	Full
		1994-96	3.62	0.09	40%	Full
		1997+	3.55	0.09	40%	Full
	HDDV		Same as Low Altitude			
Controlled Case: (1.2/1.7; 6.0/5.0)	LDGT		Same as Low Altitude			
	LDDT		Same as Low Altitude			
	HDGV	1987	Same as Base Case			
		1988	3.65	0.10	40%	Full
		1989-90	3.62	0.10	40%	Full
		1991-93	2.97	0.09	40%	Full
		1994-96	2.89	0.09	40%	Full
		1997+	2.83	0.09	40%	Full
	HDDV		Same as Low Altitude			

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[1] Zero-mile emissions (g/mi).
[2] Deterioration rate (g/mi-10K mi).
[3] Selective Enforcement Audit.
[4] Certification to half or full useful life.

CHAPTER 5

COST EFFECTIVENESS

The cost effectiveness of an action is the measure of its relative economic efficiency toward achieving a specified goal. It is primarily useful in comparing alternative means of achieving that goal. The cost effectiveness of the final particulate and NOx standards analyzed in this report will be the subject of this chapter. Before the final analysis, an overview of the cost-effectiveness analysis in the Draft Regulatory Impact Analysis (RIA) and a summary and analysis of the comments received will be presented.

I. Overview of NPRM Analysis

In the Draft RIA, EPA determined the cost effectiveness of the proposed standards in terms of the dollar cost per ton of particulate or NOx emissions controlled. These values were used to make comparisons with the cost effectiveness of other mobile and non-mobile source control strategies.

To determine cost effectiveness, two pieces of information were necessary: the costs and emissions reductions of the strategies to be examined. The costs and emissions reductions used were those associated with an average vehicle on a per-vehicle basis, rather than the total costs and reductions for the entire fleet.

The costs used were those determined in the economic analysis of the proposed standards. The emission reductions were calculated for each year of the vehicle's life by multiplying the vehicle's miles travelled (VMT) by an average per-mile emission reduction. The annual VMT values used were those determined by Energy and Environmental Analysis adjusted to reflect EPA's lifetime estimates. For heavy-duty diesel vehicles, a composite VMT was calculated by sales weighting the individual values for light, medium, and heavy heavy-duty diesel vehicles (LHDDV, MHDDV, HHDDV). The average per-mile emission reductions used were developed using information from the MOBILE2.5 emission factor model and the Diesel Particulate Study.

Two approaches were used in calculating the cost-effectiveness values for the proposed standards: an annual approach and a lifetime approach. With the annual approach, costs were allocated: 1) to each year in which emission reductions were produced, and 2) in proportion to the size of these annual reductions. The result was a cost-effectiveness value which is applicable at any point in the life of the vehicle, as well as over the vehicle's entire lifetime. This approach allowed for comparisons on a consistent basis with recent EPA cost-effectiveness estimates for other mobile and stationary source particulate control, and stationary source NOx control.

With the lifetime approach, the lifetime costs were discounted to the year of vehicle purchase and then divided by the undiscounted total lifetime emissions reductions. The lifetime approach was only used in conjunction with the proposed NOx standards to allow comparisons with past mobile source cost-effectiveness studies, where only this method was used.

Special considerations in the case of particulate matter led to the determination of several different cost-effectiveness values for each standard. Since the effects of particulate matter are highly dependent upon particle size, emissions reductions and cost-effectiveness values were determined on a total, inhalable, and fine basis.* Also, since the great majority of people who are exposed to NAAQS violations for particulate matter live in urban areas, emissions reductions and cost-effectiveness values were determined on both an urban and a nationwide basis. For the urban estimate the only change made was that emissions reductions in non-urban areas were excluded; no changes were made in the cost estimates.

II. Summary and Analysis of Comments

There were very few comments received that dealt specifically with the cost-effectiveness methodology and procedures used in the Draft RIA. Comments received on the cost-effectiveness estimates that primarily address either the costs of control, or the emissions reductions obtained, have been reviewed in the respective chapters on Economic and Environmental Impact.

There remained only three comments specific to cost effectiveness. The Department of Energy (DOE) presented its own cost-effectiveness estimates that indicated that EPA's estimates may be somewhat low. In their methodology, the costs used were the undiscounted costs of control, and the standards considered differ slightly from those that EPA considered.

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* Total particulate is all suspended particulate matter regardless of diameter, inhalable particulate is considered to be all particulate matter less than 10 micrometers in diameter, and fine particulate is considered to be all particulate matter less than 2.5 micrometers in diameter.

Several environmental groups called attention to the fact that the cost-effectiveness estimates for the 0.25 g/BHP-hr and the 0.1 g/BHP-hr standard for urban HDDEs in 1990 were equivalent. Based upon this, they questioned EPA's choice of the more lenient level of control. Finally, DOE took issue with the alleged use of a 100 percent discount rate for NOx emissions from elevated stationary sources. In their opinion, this effectively renders any comparison of cost-effectiveness between mobile and stationary sources meaningless.

DOE's practice of using undiscounted costs appears inappropriate to EPA, considering the basic economic concept of the time value of money. Since DOE did not present its cost estimates in a detailed fashion, it is not possible to determine how much of the difference in cost-effectiveness values can be explained by this difference in accounting methods. In any case, even if the basic technological economic, and environmental concepts were the same, the use of undiscounted costs will lead to higher cost-effectiveness values. Since there is no apparent reason for using this approach, it will not be considered further.

In the Draft RIA, EPA did estimate the same value for the cost effectiveness of a 0.25 g/BHP-hr and a 0.1 g/BHP-hr particulate standard for urban HDDEs in 1990. However, EPA did indicate that it believed that in fact the more stringent 0.1 g/BHP-hr standard would actually be less cost effective, for several reasons. The maximum benefit and least cost applications would have already been used to meet the 0.25 g/BHP-hr standard (with averaging), so that subsequent use of traps on additional engines might be somewhat less cost effective. Other factors cited which argued for higher cost at the 0.10 g/BHP-hr level are greater development costs, the need to design to lower low mileage-target emission levels, the use of higher quality components, the probable need for more frequent trap regeneration, and the increased risks associated with in-use compliance.

As will be seen in the updated analyses here and in the Alternatives Chapter, the cost effectiveness of a 0.10 g/BHP-hr standard does turn out to be somewhat worse than that of a 0.25 g/BHP-hr standard, confirming EPA's original position. It must also be noted that cost effectiveness is only one factor used by EPA in deciding between control options; technological feasibility has been the primary basis for the decisions in this rulemaking because of the statutory provisions governing both the NOx and particulate standards. It was on the basis of technological constraints that EPA decided against a 0.10 g/BHP-hr standard for 1990.

Contrary to the assertion by DOE, EPA did not discount the emissions reductions from stationary sources of NOx anywhere in its cost-effectiveness analysis. While some degree of discounting emissions reductions based upon spatial considerations may be appropriate in comparing the cost effectiveness on an urban basis, where stationary sources have relatively little impact upon breathing zone concentrations of NO_2, this would be less appropriate for regional scale considerations. Therefore, this analysis has not discounted the NOx emissions reductions from stationary sources when making comparisons of cost effectiveness.

III. Updated Cost Effectiveness Analysis

A. Changes in Analysis

There has been no basic change in the methodology used to determine cost effectiveness. The bases for determining the costs and emissions reductions to be used in the cost-effectiveness analysis remain the same, with their values changing only so much as the estimates have been improved.

In the Draft RIA, the differences between annualized and lifetime cost effectiveness were explained thoroughly. Mathematically, the difference lies solely in how the benefits, i.e., emissions reductions, are handled. Lifetime cost effectiveness reflects the case in which the emissions reductions are undiscounted; annualized cost effectiveness reflects the case in which the emissions reductions are discounted at the same rates as the costs.

Discounting emissions reductions assumes that the emissions reductions are worth more at the present time than in the future. For NOx, where exceedances of the ambient standard for NO_2 are projected in 1995 and 2000, but not presently, emissions reductions may actually be worth more in the future than they would be now. In the case of particulate matter, for which many areas of the country already exceed the ambient standard, this is not the case, and it could be argued that the sooner reductions are obtained the better. Thus, it is not clear to EPA if, or how much emissions reductions should be discounted over time. Therefore, the estimates of cost effectiveness in the final analysis are shown using several different discount rates for the emissions reductions. The use of various discount rates here allows for proper comparisons of cost effectiveness to other mobile and stationary source controls to be made, and for the sensitivity of the cost effectiveness to the discount rates to be established.

In the Draft RIA, the costs and emissions reductions estimates for the later year, 1990, standards were presented as incremental to the values for the 1987 standards. This yielded an incremental, or marginal cost effectiveness. In the final analysis of this chapter, this has also been done for the 1991 and 1994 standards, and is referred to as the marginal cost effectiveness.* In addition, cost-effectiveness values for the combined standards have also been determined for these later year standards, and are referred to as the total cost effectiveness.

Updated estimates of the expected annual and lifetime per average vehicle VMT are shown in Table 5-1. The VMT for HDGVs has not changed since the Draft RIA, and the estimates for line-haul truck VMT are the same as for HHDDVs in the Draft RIA. The estimates shown for non-line-haul trucks for the various model years were determined by taking weighted sums across the VMTs for LHDDVs and MHDDVs as given in the Draft RIA. The weightings were derived from projected sales fractions in each year by class, and corresponding projected diesel sales fractions.[1] As these change over time, so does the average VMT for non-line-hauls as a whole. For LDT_1 and LDT_2, separate estimates of VMT were derived, which was not done in the Draft RIA. These were derived by taking the annual average mileage accumulation rates in MOBILE3 and multiplying each year's VMT by a survival fraction derived from the registration data in MOBILE3.[2] The VMT for urban buses has been updated to reflect more recent EPA data.[1]

The emission rates for the proposed standards vary over the life of the vehicle and are summarized in Table 5-2. The particulate equations were derived using the methodology as described in the Diesel Particulate Study.[4] For NOx, the values are derived from the MOBILE3 emission factor model, and represent the actual in-use emissions including misfueling and tampering.[2] The slight difference in form for particulate and NOx reflects the differences in how the emission rates for these two different pollutants are determined. Note here that varying emission rates for each year of the vehicle's life are being used in this analysis; in the earlier analysis an average rate determined at the vehicle's half life was used. This change leads to improvements in the accuracy of the estimates.

B. Results of Updated Analysis

The emission reductions and cost-effectiveness estimates for the NOx and particulate standards are shown in Tables 5-3 and 5-4, along with the costs from the Economic Impact chapter. These costs represent the net present value in the year of sale to the consumer, using a 10 percent discount rate. It includes both the first price increase and increased

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* 1991 standards marginal from the 1988 standards, 1994 standard marginal from the 1991 standard.

Table 5-1

Annual and Lifetime Per Average Vehicle VMT (miles)[1]

Vehicle Age	LDT_1	LDT_2	HDGE	HDDE Non-Line-Haul[2,3] 1988	1991	1994	Bus	Line-Haul
1	17,394	18,352	15,590	22,077	21,971	22,042	45,000	64,720
2	15,373	16,149	14,040	21,269	21,163	21,234	45,000	63,790
3	13,553	14,175	12,630	20,724	20,618	20,689	45,000	62,850
4	11,917	12,409	11,000	19,489	19,388	19,456	45,000	54,870
5	10,447	10,831	9,960	17,871	17,777	17,840	45,000	47,700
6	9,127	9,421	8,210	15,949	15,864	15,921	45,000	41,000
7	7,944	8,164	7,060	14,045	13,969	14,020	45,000	35,310
8	6,884	7,044	6,050	12,021	11,957	12,000	45,000	39,320
9	5,937	6,048	5,170	9,972	9,721	9,755	45,000	25,910
10	4,986	5,058	4,339	7,499	7,460	7,486	45,000	19,510
11	4,239	4,281	3,570	5,691	5,662	5,682	45,000	17,840
12	3,574	3,594	2,960	4,393	4,371	4,386	45,000	14,910
13	2,983	2,987	2,410	3,841	3,818	3,833	0	12,130
14	2,459	2,451	1,960	2,727	2,715	2,723	0	9,870
15	1,996	1,980	1,680	2,118	2,108	2,115	0	7,980
16	1,587	1,568	1,250	1,630	1,623	1,628	0	5,310
17	1,226	1,206	980	1,168	1,163	1,166	0	4,970
18	910	891	750	952	949	951	0	3,790
19	633	617	520	703	699	702	0	2,890
20	479	465	340	423	421	422	0	2,070
Total Expected Lifetime Miles	123,648	127,691	110,190	184,363	183,418	184,048	540,000	527,740

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[1] Urban fraction of travel for HDDVs: Non-line hauls = .475, line hauls = .176, buses = 1.000, all = .288

[2] Changes in VMT by model year due to changes in relative total sales fractions of heavy-duty classes IIB-V and VI-VIIA.

[3] HDDE all classes VMT can be approximated by taking a weighted average of non-line hauls and line hauls. Relative weights are .635 and .365, respectively.

Table 5-2

Annual Per Mile Emission Rates (grams/mile)

Particulate

	Vehicle Type	Model Year	Emission Rate[1]	
			ZM[2]	DR[3]
Base Case: (no further control)	Non-Line-Haul	1988	1.1765	.0000
		1991	1.1233	.0000
		1994	1.502	.0000
	Line-Haul	1988	2.1917	.0000
		1991	2.1784	.0000
		1994	2.1581	.0000
	Urban Bus	1988	2.6586	.0000
		1991	2.6502	.0000
		1994	2.6334	.0000
1988 Standard 0.60 g/BHP-hr	Non-Line-Haul	1988	1.0084	.0000
		1991	.9628	.0000
		1994	.9472	.0000
	Line-Haul	1988	1.8786	.0000
		1991	1.8672	.0000
		1994	1.8499	.0000
	Urban Bus	1988	2.2788	.0000
		1991	2.2716	.0000
		1994	2.2572	.0000
1991 Standard 0.25 g/BHP-hr exc. 0.10 g/BHP-hr for urban bus	Non-Line-Haul	1991	.4012	.0084
		1994	.3947	.0083
	Line-Haul	1991	.7780	.0218
		1994	.7708	.0216
	Urban Bus	1991	.9465	.0265
		1994	.9405	.0263
1994 standard 0.10 g/BHP-hr	Non-Line-Haul	1994	.1579	.0216
	Line-Haul	1994	.3083	.0308
	Urban Bus	1994	.3762	.0376

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[1] Emission rates vary slightly with model year due to changes in the conversion factors between g/BHP-hr and g/mi.

[2] Zero-mile emissions (g/mi)

[3] Deterioration rate (g/mi x (years-0.5))

Table 5-2, Cont'd

Annual Per Mile Emission Rates (grams/mile)

NOx

	Vehicle Type	Model Year	Emission Rate[1]	
			ZM[2]	DR[3]
Base Case:	LDGT$_1$	1988	1.94	.0136
2.3 g/mi LDT	LDDT$_1$	1988	1.76	.0030
10.7 g/BHP-hr HDE	LDGT$_2$	1988	1.94	.0136
	LDDT$_2$	1988	1.97	.0030
	HDGE	1988	4.89	.0132
		1991	4.77	.0122
	HDDE	1988	23.18	.0000
		1991	22.84	.0000
1988 Standard	LDGT$_1$	1988	1.19	.0107
1.2/1.7 g/mi	LDDT$_1$	1888	0.94	.0030
LDT$_1$, LDT$_2$	LDGT$_2$	1988	1.54	.0107
	LDDT$_2$	1988	1.32	.0030
6.0 g/BHP-hr HDE	HDGE	1988	4.67	.0132
		1991	4.56	.0122
	HDDE	1988	13.05	.0050
		1991	12.86	.0050
1991 Standard	HDGE	1991	3.82	.0122
5.0 g/BHP-hr HDE	HDDE	1991	10.73	.0050

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[1] Emission rates vary slightly with model year due to changes in the conversion factors between g/BHP-hr and g/mi.

[2] Zero-mile emissions (g/mi)

[3] Deterioration rate (g/mi x 1000 mi)

Table 5-3

Urban Particulate Cost Effectiveness

Option (g/BHP-hr)	Costs($)[1]	Discounted Benefits (tons) Rate			Cost Effectiveness ($/ton) Discount Rates for Benefits		
		0%	5%	10%	0%	5%	10%
1988: 0.60	46	.026	.021	.017	1770	2190	2710
1988: 0.60 1991: 0.25 0.10 for urban buses	671-774 (625-728)[2]	.111 (.085)	.090 (.070)	.075 (.058)	6050-6970 (7350-8560)	7460-8600 (8930-10400)	8950-10300 (10800-12600)
Bus Only 1991	1758[3] (1712)	1.217 (.991)	.953 (.779)	.775 (.635)	1440 (1730)	1840 (2200)	2270 (2700)
1988: 0.60 1991: 0.25 0.10 for urban buses 1994: 0.10	966-1122[4] (296-347)	.137 (.027)	.111 (.022)	.094 (.019)	7050-8190 (11000-12900)	8700-10100 (13500-15800)	10300-11900 (15600-18300)

---

[1] Costs represent net present value in year of sale of the total cost to consumer, using a constant 10 percent discount rate.

[2] Figures in parentheses indicate marginal values from standard levels of 0.60 g/BHP-hr in 1988 and 0.25 g/BHP-hr in 1991 (0.10 g/BHP-hr for urban buses).

[3] Cost, benefits, and cost effectiveness for urban buses only.

[4] This value calculated by taking a weighted average of the heavy-duty bus and non-bus trap equipped costs to go from no control to 0.10 g/BHP-hr in 1994.

Table 5-4

NOx Cost Effectiveness

Option (g/BHP-hr)	Costs($)[1]	Discounted Benefits (tons) Rate 0%	5%	10%	Cost Effectiveness ($/ton) Discount Rates for Benefits 0%	5%	10%
LDT: 1.2/1.7, 1988	28	.108	.085	.070	263	334	405
HDE: 6.0, 1988	36	1.494	1.211	1.021	24	30	35
HDG	7	.027	.022	.018	278	341	417
HDD	69	3.181	2.578	2.175	22	27	32
HDE: 6.0, 1988	79-166	1.989	1.610	1.357	40-83	49-103	58-122
5.0, 1991	(41-128)[2]	(.408)	(.328)	(.275)	(100-314)	(125-390)	(149-465)
HDG	21	.115	.093	.079	183	227	267
	(14)	(.090)	(.073)	(.061)	(151)	(186)	(223)
HDD	137-311	3.863	3.126	2.634	35-81	44-99	52-118
	(68-242)	(.726)	(.583)	(.488)	(94-333)	(117-415)	(139-496)

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[1] Costs represent net present value in year of sale of the total cost to consumer, using a constant 10 percent discount rate.

[2] Figures in parenthesis indicate marginal values from standard level of 6.0 g/BHP-hr in 1988 for HDEs.

operating costs. Where applicable, the total and marginal values for each standard level have been presented. For the particulate standards, only the urban cost effectiveness is given in this analysis as the nationwide value has not been used in comparisons with other sources.

The costs and cost-effectiveness values presented here represent the long-term values for each of the standards as the fleet stabilizes in its response to the change in standards. In the short term, the costs associated with the standards will be somewhat higher as discussed in the Economic Impact chapter. This would in turn result in higher cost-effectiveness estimates in the short term.

The discount rate used for the benefits can have a marked effect on the benefits and cost-effectiveness values. As seen in the tables, this results in a 40-60 percent increase in cost-effectiveness values in comparing results using undiscounted benefits and those discounted at 10 percent. The cost estimates from Chapter 3 used a 10 percent discount rate. Thus, the cost effectiveness estimates at a 0 percent discount rate are equivalent to the lifetime cost-effectiveness values as described in the Draft RIA, and those at a 10 percent discount rate are equivalent to annualized cost-effectiveness values.

C. Comparison to Other Control Strategies

1. Particulate

Table 5-5 presents an update of Table 6-5 in the Draft RIA comparing the relative economic efficiencies of controlling particulate emissions from other mobile and stationary sources. Other than updating the values from 1983 to 1985 dollars, based upon the consumer's price index for new cars and the producer's price index for industrial commodities (5.9 percent and 2.4 percent respectively) no changes have been made in the estimates for other sources taken from the DPS report.[5] As in the Draft RIA, the comparison is presented on the basis of total, inhalable, and fine particulate; and the stationary values have been adjusted to reflect the relative breathing zone air quality impact of those emission compared to that of diesel emissions.[3,4]

The updated estimates of the cost-effectiveness values for particulate control for HDDV are generally equivalant to those in the Draft RIA. Therfore, as would be expected, the figures in Table 5-5 suggest that HDDV controls remain quite favorable when compared to stationary source controls, regardless of the size of particulate examined. Only the control of wet cement kilns appears to be significantly more cost effective than any of the HDDV standards. Thus, it is a fair conclusion to state

Table 5-5

Annual Cost Effectiveness Comparison for Particulate Control Of Urban HDDVs and Other Mobile and Stationary Sources ($/ton)[1,2,3,4]

Sources[5]	Particulate Size Basis[6] Total	 Inhalable	 Fine
Cement Kiln	1	770	1840
Bus Only 1991 Standard	2270	2270	2270
HDDE 1988 Standard	2710	2710	2710
LDDT (.26,1987)	9530	9530	9530
HDDE 1991 Standard	9630	9630	9630
HDDE 1994 Standard	11100	11100	11100
LDDV (.2,1987)	11100	11100	11100
Kraft Smelt Tank	12300	14700	22200
Electric Arc Furnace	9740	15300	15400
Borax Fusing Furnace	13600	17900	20200
Industrial Boiler	29900	42000	126000
Kraft Recovery Furnace	33200	42400	60500
Lime Kiln (baghouse)	48400	59500	93000
Electric Utility	48600	70000	159000
Lime Kiln (ESP)	77600	96700	156000

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[1] Stationary sources are discounted to reflect their relative ground level effect.

[2] 1985 dollars.

[3] Emissions reductions discounted 10 percent.

[4] For simplification, the midpoint of the ranges were used, where applicable.

[5] Ranking based upon inhalable particulate values.

[6] See References 3 and 4 for other mobile and stationary sources.

that the HDDV particulate standards are quite cost effective when compared to stationary source and other mobile source controls.

2. NOx

Tables 5-6 and 5-7 present updates of Tables 6-8 and 6-9 in the Draft RIA comparing the relative economic efficiencies of controlling NOx emissions from various mobile and stationary sources. The values for the more stringent standard for LDVs has been updated from 1984 to 1985 dollars by 2.4 percent, based upon the consumer's price index for new cars, but are unchanged otherwise.[5] The values associated with I/M programs for LDVs represent more recent EPA estimates.[10] The cost effectiveness values associated with the stationary source controls of NOx have been updated to reflect more recent analysis performed by EPA's Office of Air Quality Planning and Standards, the South Coast Air Quality Management District, and EPA Region IX. [6,7,8,9]

As with diesel particulate, the updated estimates for cost effectiveness of the NOx standards are generally equivalent in the updated analysis compared to the results in the Draft RIA. The estimates for HDGEs have increased from $15 to $278/ton and from $55 to $151/ton* for the early and later year standards.[3] This reflects changes in the emission factors from MOBILE2.5 to MOBILE3 and increases in the costs associated with the HDGV NOx standards. Since the emissions reductions and costs associated with the HDGE NOx standards are small, even slight changes in their estimates can have large effects on the cost effectiveness as has been seen to be the case.

The final NOx standards for LDTs and HDEs remain quite favorable in cost-effectiveness comparisons to other mobile and stationary source controls of NOx. The final NOx standards for LDTs and HDEs have lower cost-effectiveness values than almost all of the other mobile or stationary source control options. If the stationary source NOx emissions were discounted to reflect their relative ground level effect, as was done for particulate, the cost effectiveness of the proposed LDT and HDE NOx standard would compare even more favorably.

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* Using undiscounted benefits.

Table 5-6

Lifetime Effectiveness Comparison
of NOx Control for Mobile Sources

Source[1]	Cost Effectiveness ($/ton)[2,3]
HDDE 1988 Standard	22
HDDE 1991 Standard	35-81
HDGE 1991 Standard	183
LDT 1988 Standard	263
HDGE 1988 Standard	278
LDVs (I/M, where presently exists for HC/CO)	527[4]
LDVs (I/M, where none presently for HC/CO)	2290[4]
LDVs (1.09 to 0.4 g/mi)	2460[5]

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[1] Ranked according to midpoint of range.

[2] 1985 dollars.

[3] Emissions reductions undiscounted.

[4] See Reference 10.

[5] "Cost Effectiveness of Large Aircraft Engine Emission Controls - Final Report," U.S. EPA, OAR, OMS, ECTD, December 1979.

Table 5-7

Annual Cost-Effectiveness Comparisons for NOx Control of LDTs and HDEs and Stationary Sources

Source[1]	Cost Effectiveness ($/ton)[2,3]
HDDE 1988 Standard	32
HDDE 1991 Standard	52-118
Industrial Residual Oil Boilers	162[4]
HDGE 1991 Standard	267
LDT 1988 Standard	405
HDGE 1988 Standard	417
Industrial Coal Boilers	456[4]
Internal Combustion Engines	507[4]
Cement Kilns (Calif.)	812[5]
Stationary Gas Turbine	1010[4]
Internal Combustion Engines (Calif.)	1320[5]
Glass Melting Furnaces (Calif.)	3550[5]
Refinery Heaters and Boilers (Calif.)	11200[5]

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[1] Ranked according to midpoint of range

[2] 1985 dollars

[3] Emissions reductions discounted 10%

[4] See References 6 and 7

[5] For applications in Southern California, see Reference 8 and 9

D. Conclusion

The cost effectiveness of the particulate and NOx standards is favorable when compared with other mobile source control strategies. This is also true when these standards are compared with stationary sources. Therefore, based on this above analysis, the standards appear to be a cost-effective means of reducing particulate and NOx emissions compared to controlling these pollutants from other sources.

References

1. "Heavy-Duty Vehicle Emission Conversion Factors 1962-1997," Smith, M.C. IV, U.S. EPA, OAR, OMS, ECTD, SDSB, EPA-AA-SDSB-4-1, August 1984.

2. "User's Guide to MOBILE3," U.S. EPA, EPA-460/3-84-002, June 1984.

3. "Draft Regulatory Impact Analysis and Oxides of Nitrogen Pollutant Specific Study Control of Air Pollution From New Motor Vehicles and New Motor Vehicle Engines: Gaseous Emission Regulations for 1987 and Later Model Year Light-Duty Vehicles, Light-Duty Trucks, and Heavy-Duty Engines; Particulate Emission Regulations for 1987 and Later Model Year Heavy-Duty Diesel Engines," U.S. EPA, OAR, OMS, October 1984.

4. "Diesel Particulate Study," U.S. EPA, OAR, OMS, ECTD, SDSB, October 1983.

5. "Economic Report of the President," Bureau of Labor Statistics, February 1985.

6. "Standards of Performance for New Stationary Sources; Industrial-Commerical-Institutional Steam Generating Units; Proposed Rule and Public Hearing," EPA CFR Part 60, Federal Register, Tuesday, June 19, 1984.

7. Phone Conversation between Fred Porter and Doug Bell, EPA Office of Air Quality Planning and Standards, and Dale S. Rothman, EPA Office of Mobile Sources, February 1, 1985.

8. Phone Conversation between Bill Wruble, EPA Region IX, and Dale S. Rothman, EPA Office of Mobile Sources, February 5, 1985.

9. "Final Air Quality Management Plan: 1982 Revision Appendix VII A," South Coast Air Quality Management District.

10. "Effectiveness of I/M for NOx Emission Control," EPA Technical Memo from Charles Gray, OMSAPC, ECTD, to Joseph Padgett, OQAPS, SASD, January 12, 1981.

CHAPTER 6

ALTERNATIVE ACTIONS

I. Introduction

In preparing the final rule for new NOx and particulate standards, EPA considered a wide variety of alternatives. The evaluation of alternatives is intended to identify the best approach available to EPA and is an essential element of a Regulatory Impact Analysis performed under Executive Order 12291.

Structurally, this chapter is divided into three broad sections. In the first section, alternatives which were considered for LDT NOx emission standards are addressed. Alternative NOx standards for HDEs are addressed in the second section of the chapter and alternative particulate standards for HDDEs are addressed in the third and final section of the chapter. In all three sections, the intent is to develop key information concerning the costs, emissions impacts, and cost effectiveness of each alternative. Discussion and evaluation of the options in light of this information can be found in the preamble to the final rule.

The methodologies used in developing the emissions, costs and cost-effectiveness values for the alternatives were the same as those detailed in respective chapters of this document. Since these methodologies were fully detailed in the previous chapters, they are not reproduced here.

II. Alternative Light-Duty Truck (LDT) NOx Standards

The alternative NOx standards for LDTs which were considered for this final rule were: 1) to retain the existing NOx standard of 2.3 g/mi, 2) to implement, effective with the 1988 model year, NOx standards of 1.2 g/mi for LDT_1s and 1.7 g/mi for LDT_2 and 3) to implement, effective with the 1988 model year a NOx standard of 1.2 g/mi for LDT_1s and to retain the existing standard of 2.3 g/mi for LDT_2s. Since the implementation of LDT standards for 1987, as proposed, has been ruled out on the basis of leadtime constraints, no other detailed analysis of this option was prepared.

The key facts (emissions, technical difficulty, cost, and cost effectiveness) pertaining to each of the alternatives are summarized in Table 6-1.

Table 6-1

Chart of Key Facts for LDT NOx Options

Option (g/BHP-hr)	Nationwide NOx Emissions (1000 tons/yr)		Ten City NOx Emissions (tons/year)		Technical Difficulty	Cost per Vehicle	Cost Effectiveness ($/ton) [3]	
	1995[1]	2000[1]	1995[1]	2000[1]			Undisc.	10% Disc.
1. 2.3 (no further control)	24,804(8%) [2]	26,918(17%) [2]	900,600(+2%) [2]	972,100(+10%) [2]	None	--	--	--
2. LDT_1: 1.2 LDT_2: 1.7 in 1988	24,593(7%)	26,605(16%)	877,300(-1%)	937,500(+6%)	Low	28	263	405
3. LDT_1: 1.2 LDT_2: 2.3 in 1988	24,668(7%)	26,677(16%)	885,500(0%)	952,200(+8%)	Low	17	233	359
4. LDT_1: 1.2 LDT_2: 1.7 in 1988 (averaging)					Improved over 2	Improved over 2	Improved over 2	Improve. over 2

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[1] Assumes a 6.0 g/BHP-hr standard in 1988 for HDEs.

[2] Figures in parentheses indicate increase over 1982 levels. 1982 NOx Emissions: Ten City Total - 884,800, Nationwide Total - 22,981,000.

Under the first alternative (retain the existing NOx standard for LDTs), costs would be zero since no actions would be required by the manufacturers and reductions in emissions would also be zero. In the second alternative, shown in Table 6-1 as Option 2, the effects on emissions are those which are projected to accrue from the implementation of the 1.2 g/mi standard for LDT_1s and the 1.7 g/mi standard for LDT_2s. The costs are the total costs associated with the use of the technologies* necessary for achieving compliance with the applicable standard on both groups of LDTs, distributed over the total number of LDTs to arrive at an average cost per LDT. Under the third alternative (1.2 g/mi for LDT_1s and 2.3 g/mi for LDT_2s), emission benefits are attributable to the 1.2 g/mi standard applicable to LDT_1s and the cost per vehicle was developed from the total costs associated with the 1.2 g/mi standard applicable to LDT_1s with distribution of the benefits and costs over the total fleet of LDTs.

In the fourth alternative (the alternative adopted in the final rule), emissions averaging has been included. Since averaging will provide manufacturers with greater degrees of freedom in the selection of specific combinations of technologies and calibrations used on each engine than would be available without averaging, the costs of complying with this alternative while being lower than those associated with the third alternative can only be developed on an engine-by-engine basis. At this level of detail, i.e., on an engine-by-engine basis, the information necessary for optimizing the trade-offs between costs and emissions by engine and the subsequent integration into the determination of average compliance with the standard is only available to each manufacturer for their specific engines. EPA has, therefore, not attempted to quantify the exact magnitude of the reductions in costs relative to the non-averaging alternative and consequently the improvements in cost effectiveness attributable to the fourth alternative.

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* For LDGTs, this mean recalibration of existing three-way closed-loop systems and the conversion to three-way closed-loop systems where these systems are not already in use, and for LDDTs the addition of EGR where EGR is not already in use and the conversion to electronically controlled EGR where EGR is already in use.

III. Alternative Heavy-Duty Engine (HDE) NOx Standards

The alternative NOx standards considered for heavy-duty engines were; 1) to retain the existing standards, 2) to implement a NOx standard of 6.0 g/BHP-hr in 1988 with no subsequent change in this standard, 3) to implement a NOx standard of 6.0 g/BHP-hr in 1988 followed by implementation of a 5.0 g/BHP-hr NOx standard in 1991 with no subsequent change in the 5.0 standard and 4) the same standards and implementation dates as alternative 3, but with the addition of average starting with implementation of the 5.0 g/BHP-hr standard in 1991. As was the case for light-duty trucks, the originally proposed dates for possible new standards of 1987 and 1990 have been eliminated due to leadtime constraints.

The key facts pertaining to each of the HDE NOx standard alternatives are shown in Table 6-2. Differences in the emissions, costs and cost-effectiveness values between the alternatives result from the following. Under the first alternative (retain the existing standard), costs and effects on emissions would both be zero. For the second alternative the costs are limited to those associated with the application of the changes* necessary for compliance with the 6.0 g/BHP-hr standard as shown in Chapter 2 with the effects on emissions being projected into the 1995 and 2000 timeframes. In the third alternative, the marginal costs shown are the incremental increase of the 5.0 g/BHP-hr standard beyond those of the 6.0 g/BHP-hr standard resulting from further additions and/or modifications of the combinations of technologies previously identified at the 6.0 g/BHP-hr standard level and the benefits are those as calculated in Chapter 4. The overall cost per engine in Option 3 is the sum of the incremental cost for Option 3 and that for Option 2, treated as if it were added in 1991. Since the sales weighting between gas and diesel engines changes between 1988 and 1991, the overall cost shown is slightly different than a simple sum of the costs of Options 2 and 3. Averaging for HDE NOx was treated in the same fashion as was light-duty truck NOx averaging.

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* For gasoline HDEs, the changes used are ignition timing retard and the recalibration of EGR systems. for diesel HDEs, combinations of the following technologies would be used: injection timing retard, addition of aftercooling to some engines, addition of variable injection timing to some engines, and modification of variable injection timing on some engines already equipped with this feature and improvements in aftercooling and turbocharging on some engines already equipped with these features.

Table 6-2

Chart of Key Facts for HDE NOx Options

Option (g/BHP-hr)	Nationwide NOx Emissions (1000 tons/yr)		Ten City NOx Emissions (tons/year)		Technical Difficulty	Cost per Vehicle[3]	Cost Effectiveness ($/ton)[3]	
	1995[1]	2000[1]	1995[1]	2000[1]			Undisc.	10% Disc.
1. 10.7 (No further control)	26,007(13%)[2]	28,367(23%)[2]	959,500(+8%)[2]	1,045,800(+18%)[2]	None	--	--	--
2. 1988: 6.0	24,804(8%)	26,918(17%)	900,600(+2%)	972,100(+10%)	Low	36	24	35
3. 1988: 6.0 1991: 5.0	24,567(7%)	26,530(15%)	887,600(0%)	950,100(+7%)	Moderately High	79-166 (41-128)	40-83 (100-314)	58-122 (149-465)[4]
4. 1988: 6.0 1991: 5.0 (averaging)	24,567(7%)	26,530(15%)	887,600(0%)	950,100(+7%)	Improved over 3	Improved over 3	Improved over 3	Improved over 3

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[1] Assumes LDT standard of 2.3 g/mi.

[2] Figures in parentheses indicate increase over 1982 levels. 1982 NOx Emissions: Ten City Total - 884,800, Nationwide total - 22,981,000.

[3] Figures used represent long-term effect of the standards. Cost in first year or two will be somewhat higher due to a short-term fuel economy effect.

[4] Figures in parentheses indicate marginal cost and C/E relative to Option 2.

IV. Alternative Heavy-Duty Diesel Engine (HDDE) Particulate Standards

The originally proposed implementation dates of 1987 and 1990 have been revised to 1988 and 1991, respectively due to leadtime constraints. Therefore, the alternative particulate standards for HDDEs which were considered for this final rule are as follows: 1) the introduction of no standard(s) for particulate emissions, 2) implementation of an engine-out particulate standard of 0.6 g/BHP-hr effective with the 1988 model year with no subsequent reduction in the standard, 3) implementation of an engine-out standard of 0.6 g/BHP-hr in the 1988 model year and the implementation of a 0.25 g/BHP-hr standard in 1991 achieved through the use of particulate trap technology, with averaging being allowed starting with the 1991 model year, 4) the same as alternative three but with the addition of a 0.10 g/BHP-hr standard for urban buses without the availability of averaging for buses, 5) the same as alternative three but with the addition of a 0.50 g/BHP-hr engine-out standard for line-haul HDDEs, 6) implementation of an engine-out particulate standard of 0.6 g/BHP-hr in 1988 and the implementation of a 0.10 g/BHP-hr standard in 1991 achieved through the use of particulate trap technology with averaging being allowed starting in 1991 and 7) the same as alternative three (0.6 g/BHP-hr in 1988, 0.25 g/BHP-hr with averaging in 1991 for all HDDEs except urban buses, and 0.10 g/BHP-hr for urban buses without averaging), plus the implementation of a 0.10 g/BHP-hr standard effective in 1994, with averaging for all HDDEs except urban buses where the 0.10 g/BHP-hr, non-averaging standard would be retained.

The key facts pertaining to the alternative particulate standards which were considered are shown in Table 6-3. The factors bearing on the differences in emissions, costs and cost-effectiveness values between alternatives are discussed below.

In the cost of the first alternative, costs are zero since no action would be required on the part of the manufacturers. Changes in particulate emissions are also zero. The cost of the 0.6 g/BHP-hr particulate standard was developed from the cost of the changes, modifications, and where required, additions in hardware necessary* for the attainment of the standard.

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* Technologies applicable to attainment of a 0.6 g/BHP-hr particulate standard include: the addition of or modifications to variable injection timing for enhanced transient air/fuel ratio control, combustion chamber modifications and improved air swirl, improved turbochargers to enhance transient response and air flow, improved injectors and fuel injection pumps and increased injection pressures.

Table 6-3

Chart of Key Facts for HDDE Particulate Control Options

Option (g/BHP-hr)	Total Mobile Source Emissions (tons/year)		Type of Control System Required[1]	Technical Difficulty	Cost Per Vehicle[1]	Discounted Cost Effect-tiveness ($/ton)
	1995	2000				
1. No Control	87,949 (+65%) [2]	108,941 (+105%) [2]	None	None	--	--
2. 1988: 0.60	80,385 (+51%)	99,369 (+87%)	Non-trap	Low	46	2710
3A. 1988: 0.60 1991: 0.25 (A) (w/averaging (A))	61,169 (+15%)	70,557 (+33%)	60% Trap	High	631-736 (585-690)	8,890-10,400 (10,800-12,800) [3]
3B. 1988: 0.60 1991: 0.25 (A) 0.10 for urban buses	59,731 (+12%)	68,344 (+28%)	Buses: 100% Trap Other: 60% Trap	High	671-774 (625-728)	8,950-10,300 [4] (10,800-12,600)
3C. 1988: 0.60 1991: 0.25 (A) for urban HDDE's 0.50 for line-haul HDDE's	67,008 (+26%)	78,949 (+48%)	Urban: 60% Trap Other: Non-trap	Moderately High	388-491 (342-445)	7,050-8,930 (9,000-11,700)
3D. 1988: 0.60 1991: 0.10 (A)	52,933 (-0.5%)	58,209 (+9%)	100% Trap	Very High	1,211-1,382 (1,165-1,336)	12,900-14,700 (15,100-17,400) [5]
4. 1988: 0.60 1991: 0.25 (A) 0.10 for urban buses 1994: 0.10 (A)	57,230 (+8%)	59,316 (+11%)	1991: 60% Trap 1994: 90% Trap	High	966-1,122 (296-347)	10,300-11,900 (15,600-18,300) [6]

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[1] Except for Option 3D, all figures represent long-term effects of the standard. Cost figures would be somewhat greater in the early years because of greater trap usage due to higher engine-out particulate levels.

[2] Figures in parentheses indicate change from 1984 levels. 1984 Diesel PM Emissions: 53,208.

[3] Figures in parentheses indicate marginal C/E relative to Option 2, unless otherwise noted.

[4] The marginal cost and C/E for the buses, relative to Option 2, are cost = $1,712, C/E = $2,700/ton.

[5] Relative to Option 3B the incremental C/E = 24,200-26,800.

[6] Computed relative to Option 3B.

For all of the alternatives which included the introduction of a 0.25 g/BHP-hr particulate standard effective with the 1991 model year (Options 3A, 3B, 3C, and 4), the marginal cost of the 0.25 g/BHP-hr standard is the increase in cost beyond that shown for the 0.6 g/BHP-hr. It is derived from the application of particulate traps and the fuel economy effects of traps, taking into consideration the effects of averaging. Engine-out particulate levels anticipated to be achievable in the long run (i.e., following the initial couple of years) were developed. These engine-out levels were then combined with a trap efficiency of 80 percent to determine the trap application rate necessary for compliance with the 0.25 g/BHP-hr standard. The trap application rate so determined was 60 percent.

For Option 3A, where all HDDEs would be required to comply with a 0.25 g/BHP-hr particulate standard, the marginal cost per engine was derived from the sum of the total cost of applying traps to 60 percent of the engines, expressed as an average over all HDDEs. In Option 3B, the marginal per engine cost is the average cost over all engines of applying traps in 100 percent of the urban buses (which constitute 2 percent of HDDEs) plus 60 percent trap utilization on the remaining 98 percent of HDDEs. In the case of Option 3C, 36 percent of all HDDEs are considered to be in line-haul operation. The marginal cost per engine for this alternative is, therefore, the cost of applying traps at a trap installation rate of 60 percent on those HDDEs which are not used in line-haul operations (64 percent of the fleet) combined with the cost of compliance with a 0.50 g/BHP-hr standard for the line-haul engines (estimated at one-third to two-thirds the cost of a trap system). The tabulated value represents the sales weighted combination of these costs.

For Option 3D, essentially 100 percent usage of particulate traps would be required. In addition, in this timeframe EPA also estimates that some small added fuel economy penalty would be associated with a 0.10 g/BHP-hr standard effective in 1991. This value is estimated at about 0.5 percent. The marginal costs shown in Table 6-3 are, therefore, those attributable to the installation of particulate traps on all engines plus the fuel economy effects of trap usage on all HDDEs.

The marginal costs applicable to Option 4 (the alternative adopted in the final rule) are the costs relative to Option 3B of applying a sufficient number of 85 to 90 percent efficient traps in 1994 so as to achieve the 0.10 g/BHP-hr standard for all HDDEs, allowing averaging for all engines except those used in urban buses. In determining the trap application rate required for non-urban bus HDDEs, allowance was made for some expected improvements in available trap efficiency between 1991 and 1994 and slight reductions in engine-out particulate levels. The trap application rate so determined was 90 percent on non-urban bus HDDEs. In addition, this time period will allow manufacturers to overcome the additional fuel economy penalty associated with adopting 0.10 g/BHP-hr in 1991. The costs per engine represent the weighted average of the sum of the trap costs for a 90 percent trap application rate on non-urban-bus HDDEs plus the costs of a 100 percent trap application rate to the 2 percent of HDDEs used in urban buses.

The above discussions described the marginal cost for each of the alternatives. Also given are overall costs of each option, which are simply the sum of the marginal costs of that option plus any prior options included as earlier steps. For example, the overall cost of Option 4 is the sum of the marginal costs of Options 2, 3B and 4.

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Appendix A

Summary and Analysis of Comments on the Proposed Particulate Test Procedure for Heavy-Duty Diesel Engines

Summary and Analysis of Comments on the Proposed Particulate Test Procedure for Heavy-Duty Diesel Engines

Following the publication of the NPRM, the HDD manufacturers submitted written comments on the proposed particulate test procedure. Also, a meeting was held between the Engine Manufacturers Association (EMA) and EPA on January 28, 1985 during which HDD particulate test procedure details were discussed. A memorandum describing this meeting is available in Docket A-80-18. The written test procedure comments as well as the verbal comments made at this meeting are summarized and analyzed below in four groups.

The first group includes those which were well supported by data or engineering analysis and which will not affect measured particulate mass. The recommendation here is to essentially accept the test procedure revisions contained in these comments.

The second group of issues include those which were not well supported by available data or engineering analysis and where the available data indicated that the change could significantly affect measured particulate mass. The recommendation here is to deny these requests for test procedure changes, until it becomes clear that such changes will not affect particulate measurements.

The third group of issues are those upon which EPA requested comment in the proposed rule, and the fourth group are those which do not relate to Subpart N but are still related to heavy-duty engine testing.

The analysis of each issue begins with a short description of the aspect of the test procedure in question. The comments made on this aspect are then summarized. Finally, the available information relating to the issue is analyzed and a recommendation is made.

I. Recommendations Accepted by EPA

Exhaust System Length

Section 86.1327-87(f) of the proposed regulations specifies that the distance from the manifold to the end of chassis-type exhaust system should be a maximum of 12 feet. Also, the length of exhaust system tubing from exit of the chassis-type system or from the manifold to the dilution tunnel shall be no more than 12 feet (maximum), if uninsulated, or 20 feet (maximum), if insulated. This tubing shall be made of stainless steel.

Summary of Comments: Ford is concerned that: 1) 12 feet of chassis-type system may be too short for all in-use systems, and 2) two maximum exhaust system lengths are possible, depending on whether a chassis type system is used (32 feet is maximum) or if not (20 feet maximum).

EMA expressed concerned about the following three issues:

1. "EPA has addressed the issue of exhaust system design in the existing Final Rule for gaseous emissions (48 FR 52227) considering the effect of upcoming particulate control. In Section 86.1327-84(f)(2)(i) of this final rule, EPA permits a total of 32 feet length from engine to tunnel inlet."

"Engine manufacturers have all completed permanent test cell installations following these guidelines. EPA has made some significant changes in the current proposed rule (49FR @ 40314) that will cause significant modifications and undue expense. EPA states that both a chassis-type and a facility-type exhaust system may be used. It is not clear that they infer "simultaneously." If EPA intends to permit only one or the other system, then the individual lengths permitted would require major test cell modifications to most facilities."

2. EMA is also concerned that the material that was specified for the tubing is stainless steel which they believe (a) is different from the gaseous emissions rule, and (b) is not necessary.

3. EMA also requested that the rules exclude insulation in the vicinity of instrumentation such as smokemeters.

Mack also expressed concern on the issue of exhaust tubing lengths. Their position, while raised separately, is generally the same as the EMA position.

Analysis of Comments and Recommendation: The wording in the proposed test procedure regarding allowable exhaust system lengths is somewhat ambiguous. It was intended to specify a total exhaust system length of 32 feet, with the option of using either a chassis type system (with its own length limitation), a facility type system or both together.

The final rule limits the amount of uninsulated tubing to 12 feet, which limits the amount of conductive cooling that can be achieved from the tubing walls at a place where the temperature differential is greatest. Yet, having up to 12 feet of uninsulated pipe provides reasonable flexibility for engine changes without the incumberance of insulation. If the typical length of an engines chassis exhaust is greater than 12 feet, use of the typical length is permitted, but only 12 feet of it can be uninsulated.

A provision should also be made for up to 18 inches of uninsulated tubing for instrumentation (an in line smoke meter, for example) since such instrumentation is required by EPA. However, to maintain a consistent limit on uninsulated tubing, such an uninsulated portion should be counted towards the maximum total uninsulated length of 12 feet.

Based on EPA's experience, it appears that the type of tubing steel should be irrelevant for diesel particulate testing since it is soon covered with a layer of particulate and further wall contact of the exhaust stream is unlikely. The only exception would be steel with an extremely rough surface which persisted despite a layer of deposited particulate, which could occur if a rustable steel were used. This could cause additional deposition. Thus, the tubing specification should be changed to include typical in-use exhaust system materials, which could reduce costs for some laboratories. However, the steel should be free from any rust.

Thus, in summary, it is recommended that the exhaust system specifications be changed and clarified to include provisions for 1) a total length of 32 feet, 2) a system which can be either chassis or facility type, 3) no more than 12 feet of uninsulated tubing, 4) tubing in vicinity of instrumentation can be uninsulated, and 5) tubing can be made of typical in-use materials, but must be free of rust.

Dilution Air Filtering or Backpressure Measurement

Section 86.1310-87(b)(1)(iv)(B) of the proposed test procedures requires the primary and secondary dilution air to be filtered if background particulate is not measured.

Summary of Comments: EMA commented that if a manufacturer does not filter dilution air or measure and correct for background particulate, the manufacturer will only be penalizing itself and not the environment (i.e., this will cause a higher particulate emission calculation). Thus, EMA recommended that the engine manufacturer should be given the option to simply use good engineering judgment to account for background particulate (i.e., filter dilution air, measure of background particulate levels, or ensure backpressure levels are sufficiently low so as to be ignored).

Ford also believed that need for filtering or background correlation should be established by the manufacturer. It recommended monthly background checks, and if background particulate is less than 1 percent of the standard, then it is assumed to be zero and background samples need not be taken with each exhaust sample.

Analysis of Comments and Recommendations: EPA believes that filtering dilution air or accounting for background particulate levels is good engineering practice. However, if background particulate levels are very low, there will be a negligible error in the emission results. In any event, any error will only overstate true particulate emissions. Therefore, it is recommended that the manufacturer be given the option to control or account for background particulate as it sees fit.

Calculation of Measured Particulate Mass

Section 86.1342-87 of the proposed regulations states "The mass of particulates...is determined from the following equation when a heat exchanger is used (i.e. no flow compensation):

$$Pmass = (Vmix + Vsf) \times \left(\frac{P_f}{V_{sf}} - \frac{P_{bf}}{V_{bf}} \right) \times (1 - 1/DF)$$

Where:

Vmix = Total dilute exhaust volume (standard conditions)

Vsf = Total volume of sample removed from the primary tunnel

Pf = Mass of particulate on the sample filter

Pbf = Net weight of particulate on the background particulate filter

Vbf = Corrected volume of primary dilution air sampled by background particulate sampler

DF = Dilution factor

There are three issues here. They are: 1) should the particulate mass on the filter plus the background be corrected for dilution factor effects, or should just the background be corrected, 2) should the calculation be based on V_{mix} or the sum of V_{mix} and V_{sf}, and 3) which equations should be specified for systems other than flow systems with a heat exchanger.

Summary of Comments: EMA commented on all three of these issues with the following statement. "The proposed equation is both in-error and is inconsistent with all the equations published in the Final Rule for Gaseous Emissions (48FR p.52236) §86.1342-84(c). In all the equations (1) through (4) of this paragraph, HC, NOx, CO, and CO_2 mass are calculated based on V_{mix} and not on the sum of V_{mix} + V_{sf}. V_{sf} is not a significant portion of V_{mix}, typically V_{sf} is less than 0.1 percent of V_{mix} and can be ignored and it should be just as it is in the final rule for gaseous emissions. Also, all these gaseous equations correct only the background measurement by the dilution ratio effect. Therefore, the equation for Pmass should be:

$$\text{Pmass} = \text{Vmix} \times \frac{P_f}{V_{sf}} - \frac{P_{bf}}{V_{bf}} \times (1 - 1/DF)$$

Other sampling procedures will require different equations, e.g., proportional mass flow control system and systems where only secondary dilution air is filtered, manufacturers should have the option to use alternate equations compatible with their systems and good engineering practice."

Analysis of Comments and Recommendation: It is technically correct that only background should be corrected for dilution factor affects (this was a typographical error).

It is also true that the current equation only applies to certain system designs. Thus, use of other equations that are based on sound engineering principles, should be permitted for alternate systems, but subject to prior approval with the alternate system itself.

However, while V_{sf} is small for many systems, including essentially all gaseous pollutant sampling systems, with some double dilution particulate sampling systems it could be significant. Therefore, V_{sf} should continue to be included in the equation, if significant. However, little accuracy would be lost if V_{sf} were ignored if it was less than 0.5 percent of V_{mix}.

Thus, the recommendation is that 1) sampling volume (V_{sf}) be retained in the equation, if it is less than 0.5 percent of V_{mix}, 2) only background be corrected for dilution factor effects, and 3) other equations be permitted, if approved in advance by the Administrator.

Balance Requirements

Section 86.1312-87(b) of the proposed regulation requires that the balance used to determine the weights of all filters shall have a precision and readability of one microgram.

Summary of Comments: EMA does not believe that the one microgram balance is necessary because the accuracy gained does not justify the additional expense and increased weighing time associated with the one microgram balance. In addition, to EMA's knowledge there are not any one microgram electronic balances available that have weighing chambers large enough for the 90 mm or 110 mm filters that are used on the EPA transient test cycle.

EMA also presented the results of an analysis that was conducted that compared the overall accuracies expected with 1 and 10 microgram balances. The 10 microgram balance was analyzed assuming a precision of 20 micrograms. EMA concluded that although the 1 microgram balance improves the filter weighing accuracy by a factor 20, this accuracy is lost in the particulate equation where other measurements are included that have 1 percent, 2 percent, or even 3 percent uncertainty. The net effect is that the 1 microgram balance, as compared to the 10 microgram balance with a precision of 20 micrograms, reduces the error by only .02 percent, from 5.30 percent to 5.28 percent. (This was calculated with a filter loading of 4 mg.) EMA believes that this example illustrates the fact that there is little benefit in having one measurement substantially more accurate than other measurements used in the same process.

EMA also makes an argument about the cost of balances. A typical 10 microgram balance costs approximately $3,000 but a 1 microgram balance costs approximately $7,000. They feel that the additional expense of a 1 microgram balance should not be forced upon manufacturers because the above analysis does not justify it in terms of gained accuracy.

Analysis of Comments and Recommendation: EMA's analysis of errors contained in their test procedure comments appears fundamentally sound. The affect of using a balance with a precision of 20 micrograms and a readability of 10 micrograms appears minor and thus it is recommended that the test procedures be changed to reflect this.

Filter Reweighing

Section 86.1339-87 of the proposed regulations requires that if a filter is removed from the weighing chamber and not used within one hour, it must be reweighed.

Summary of Comments: EMA sees no justification for this requirement and recommends its deletion. They argue that "there can be occurrences when an unscheduled test delay occurs and filter and holder assemblies remain out of the weighing chamber for more than one hour. During this delay, the filter disc may be installed in the sealed holder and no changes in dust or moisture content could occur. If the filter assembly was installed in the test fixture during this delay and some moisture penetration and deposition could occur, more moisture deposition will occur during subsequent sampling of the exhaust gas mixture. All moisture deposition either prior to or during sampling that is condensed on the filter will become adjusted to the weighing room's moisture level during the stabilization period prior to final weighing."

Analysis of Comments and Recommendation: The purpose of the rules regarding reweighing is to reduce water vapor and particulate contamination of filters from sources other than test-generated exhaust. If a filter is installed in a completely sealed filter assembly, or a sealed filter holder assembly is placed in the sampling line through which there is no flow, then such contamination should be so negligible that filters should be able to go up to 8 hours before they would have to be reweighed. However, if these conditions of filter placement are not met, then filters should be reweighed after 1 hour. Thus, it is recommended that the requirements be changed to: 1) specify reweighing after 8 hours if the filter is in a sealed holder assembly or in a sealed assembly mounted in a sampling system through which there is no flow, and 2) specify reweighing after one hour if the above filter placement criteria are not met.

"Sandwich" Filter Handling and Weighing

Section 86.1339-87 of the proposed rules requires that both the primary and backup filter be weighed independently so that the ratio of their net weights can be determined. The backup filter net weight is deleted if it is less than 5 percent of the total.

Summary of Comments: EMA comments that "Some EMA members weigh both primary and back-up filters together as a pair. Then, after sampling, in removing filters from the holders, the back-up filter is inverted on top of the primary filter placing both faces with sample accumulation 'sandwiched' to the inside. This procedure reduces the potential of lost sample since now the filter 'sandwich' can be handled with tongs anywhere including the center. This is especially desirable with large diameter filters which tend to sag when supported at the end. Weighing as a pair will, of course, reduce the number of required weighings, but will not permit the determination of the ratio of the net weights which is the manufacturers penalty."

Analysis of Comments and Recommendation: The procedure that EMA discusses appears to be technically sound. Loss of sample from filters that are weighted individually does not appear to be a problem at the present, but the EMA procedure appears to reduce the likelihood of sample loss even further.

The rule allowing a laboratory to not count up to 5 percent of total particulate filter loading due to particulate on the back-up filter is another point that EMA brought up that also deserves analysis. Whereas this has been a part of the HDD particulate testing procedures from their inception, it is not good practice since it allows up to a 5 percent error which could easily be avoided. This change will not be made during this rulemaking because prior notice has not been given and some may consider it an increase in stringency. Nevertheless, its elimination should be considered in the future.

The recommended action on this issue is that the "sandwich" filter handling and weighing procedure be permitted.

Provision for Automatic Data Collection Systems

Section 86.1310-87(b)(5)(iii) of the proposed rules specifies that "Chart deflections should be converted to concentration before flow compensation and integration" (underlining added).

Summary of Comments: Ford feels that this does not account for automatic data collection (ADC) systems and therefore, should be changed to include chart deflections and analyzer voltage output.

Analysis of Comments and Recommendation: This section dates from a period when ADC systems were generally not used. ADC systems are now common and therefore Ford's recommendation is quite reasonable. Therefore, it is recommended that use of analyzer voltage output be permitted.

Hot-Start Restart for Reasons Other Than Engine Stall

The current regulations for gaseous emissions (Subpart N, Section 86.1336-84(c)(3)) provides for a hot-start restart if the engine stalls, but no provision is made for hot-start restart after operator error or other small malfunctions that can void a test.

Summary of Comments: Caterpillar suggested including test voiding in the wording for hot start restarts. They feel that this would improve testing efficiency.

Analysis of Comments and Recommendation: The rules regarding hot-start cycle restarts were revised to include equipment malfunctions and were published in the Federal Register as technical amendments on December 10, 1984. These changes should adequately address Caterpillar's concerns on this issue.

II. Recommendations Not Accepted by EPA

Six comments addressed aspects of the procedure which have the potential to substantially affect measured particulate. In no case was there a substantial amount of data available upon which to base a decision. However, in every case the available data indicated that measured particulate mass could be affected and thus that the current specification was necessary to prevent biased measurements and unnecessary variability. In a few cases, the analysis indicated that even the present specifications may allow undue variability in particulate measurements. These aspects of the procedure should be reevaluated in the near future.

Location of Sample Line Temperature Specifications

Section 86.1310-87(b)(1)(i)(A) of the proposed regulation specifies a maximum temperature of 125°F at the sampling zone (in the primary tunnel) for single-dilution systems, but for double dilution systems, the 125°F criteria applies at the filter face.

Summary of Comments: EMA recommends that the requirement to be below 125°F at the sample zone for single dilution be changed to refer to 125°F or less at the particulate filter, in line with the double-dilution temperature requirement. The EMA feels that this temperature limit is generic in nature and not dependent on the type of sampling system used; i.e., this temperature limit and location should also apply to single dilution systems.

EMA also presented data that they feel indicates that the sample zone temperature has no influence on the single-dilution particulate results. This data compares simultaneous samples taken with a single-dilution system and a double-dilution system. The single-dilution system had a peak sample zone temperatures in the 220°F range yet peak filter temperatures of about 110°F. The heat loss was taking place in the sample transfer tubing and filter holder. The average difference in particulate mass results between the two systems was less than 0.5 percent.

In the EMA-EPA meeting of January 28, 1985, it became apparent that the main issue here was the amount of heat transfer that can be permitted in the sample transfer sections of the single-dilution or, for that matter, the double-dilution system.

Analysis of Comments and Recommendation: EPA's diesel particulate sampling system specifications are based on several precepts, two of which relate to the issue raised by EMA. These are: 1) exhaust should be cooled to 125°F or less prior to particulate sampling, and 2) this should be done to the greatest extent possible by convection (i.e., using dilution air) as this is the manner in which exhaust from an in-use engine is cooled in the atmosphere. The issue here is not the 125°F maximum temperature but rather how to achieve it.

The criteria for heavy-duty single dilution sampling systems came from those for light-duty (LD) particulate sampling systems, which is the area where most of the data exist with respect to testing procedures. The light-duty criteria (which is a single dilution system) is a maximum temperature of 125°F or less in the dilution tunnel. This reflects EPA's desire to maximize heat transfer by convection (i.e., all cooling must take place in the tunnel) and limit conductive heat transfer (i.e., heat loss in the sample line cannot be used to reach the 125°F limit).

For heavy-duty (HD) particulate sampling, the same tunnel maximum temperature of 125°F for a single dilution system represents a direct extrapolation from LD experience and is, technically, the most desirable system. However, for HD this requires very large CVS systems (and large costs) and thus EPA has allowed the alternate, double dilution system. EPA's intent for this double dilution system is the same as for the single dilution system; to achieve the majority of cooling through convection. In establishing the specification for temperature (125°F) for this double dilution system, it was applied to the filter face rather than the tunnel since all of the tunnel flow is filtered and the end of the dilution tunnel is essentially the same as the filter face (i.e., it does not matter which is specified).

The data presented by EMA (see Table A-1) compares the particulate results from a single dilution system experiencing a minimum of 110°F of conductive cooling to results from a double dilution system which also appears to allow much conductive cooling. The double dilution system used conforms to EPA regulations, the specifications for which were made with two purposes in mind. One was to limit conductive cooling. The other was to allow reasonable lengths of transfer lines, etc., for ease of assembly and location in the test cell. It appears that the flexibility granted may have been excessive, as it was not the intent of EPA to permit excessive conductive cooling from the double dilution system. Thus, at issue is not so much the single dilution system specifications but rather those of the double dilution system, which may have to be modified in order to reduce the allowable amount of conductive cooling.

While there is a limited amount of data which shows the effect of conductive heat loss from sample transfer lines on particulate concentrations (particulate increases as the degree of conductive cooling increases),[1]* what is available

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* Numbers in brackets refer to References found at the end of this section.

Table A-1

Simultaneous Particulate Sampling - EPA Transient Test

Cycle (Hot/Cold) (H/C)		Single Dilution System			Double-Dilution System			% Dif*
		Peak Temp, °F				Temp, °F		
		Sample Zone	Filter	Part. g/BHP-hr	Part. g/BHP-hr	Peak Filter	Dilution Air-In	
Engine A - Turbocharged 6 Cyl., 4-Cycle, D.I. Diesel								
1	C	212	102	.570	.580	104	80	-1.7
2	H	220	109	.604	.603	107	83	0.2
3	H	221	109	.601	.591	109	86	1.7
4	H	221	110	.591	.595	109	85	-0.7
5	H	226	110	.608	.620	109	84	-1.9
6	H	225	110	.613	.613	109	84	0.0
7	H	225	110	.609	.606	109	84	0.5
8	C	222	106	.602	.599	100	76	0.5
9	H	218	111	.620	.624	103	80	-0.6
10	H	220	113	.603	.614	105	82	-1.8
11	H	221	109	.638	.635	101	77	0.5
12	H	223	111	.651	.629	103	78	3.5
13	H	222	110	.633	.648	102	77	-2.3
14	H	222	112	.625	.633	104	78	-1.3
15	C	213	103	.625	.631	94	73	-1.0
16	H	219	109	.613	.625	94	76	-1.9
17	H	221	111	.617	.627	103	79	-1.6
18	H	222	111	.609	.618	104	78	-1.5
19	H	222	113	.625	.622	96	80	0.5
20	H	223	114	.624	.637	104	82	-2.0
21	H	223	114	.621	.633	106	82	-1.9
Engine B - Turbocharged 8-Cyl., 2-Cycle, D.I. Diesel								
22	H	299	190	.389	.397	79	89	-2.0
23	H	302	178	.387	.381	78	90	1.6
24	H	214	136	.427	.427	79	92	0.0
25	H	174	122	.484	.460	78	92	5.2
26	H	153	109	.464	.484	75	87	-4.1

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* Percent difference, single dilution compared to double dilution.

indicates that conductive cooling should be limited to the fullest extent possible. None of it argues for further relaxations. Thus, it is recommended that no changes be made in the specifications for single dilution systems, since this system still represents that which is technically most desirable. No tightening of the specifications for the double dilution system should be made at this time, since none were proposed. However, the specifications for the double dilution system should be reevaluated in the future to determine if the degree of conductive cooling currently allowed is acceptable.

Sample Flow Specifications and Proportionality

Section 86.1310-87(b)(6), paragraphs (1)(B and c), (ii)(E)(1 and 2) and (ii)(G and H), require that the gas stream temperature into the particulate sampling system flow instrumentation and sample pumps be maintained at 77° ±9°F, and also that certain temperatures be maintained within limits of ±5°F.

The intent of these proposed requirements is to assure accurate measurement of both the exhaust sample mass extracted from the primary tunnel and the mass of the secondary dilution air entering the particulate system. This allows establishing a means for maintaining the proportionality between the primary tunnel mass flow and the extracted exhaust sample.

Summary of Comments: EMA and GM expressed in their written comments that they believe that this section of the regulations should provide system performance requirements, but should not mandate the means by which such performance is accomplished.

In the EPA/EMA meeting subsequent to the submission of the written comments, it became apparent that an additional major issue of concern is the issue of proportionality between tunnel and sample flow. EMA's position is that: 1) the proposed regulations currently permit a ±5 percent deterioration in sample flow from the set point for non-flow compensated systems, and this same ±5 percent tolerance should be permitted for flow compensated systems, and 2) a ±2 percent flow change specification is permitted for the main tunnel flow, and these two flows (tunnel and sample lines) are independent and thus the permissible limits should be added to permit a total of ±7 percent deviation from proportionality.

Analysis of Comments and Recommendation: The proposed temperature requirements for particulate sampling system flow instrumentation and sample pumps are appropriate for some systems but may not be appropriate for others. This can be addressed by retaining the current proposals for sample flow handling and measurement but adding a provision that permits alternate systems if these are shown to yield equivalent results and if approved in advanced by the Administrator. Section 86.1310-87(a)(7) contains a similar statement, but it is not clear if it pertains to particulate sample flow handling and instrumentation systems and, thus, the above clarification will be useful.

The proposed rules are not adequately clear on the limits of proportionality. The rules should be made explicit and uniform for both types of systems (flow compensated and non-flow compensated). The question is what should the specifications be.

EMA believes that tunnel flow and sample line flow are independent and therefore the tunnel flow limits (±2 percent) and nonproportional flow limits (±5 percent) should simply be added together to yield overall proportionality limits of ±7 percent. While the independence of these two errors can be debated, the issue here is not equity, but accuracy. The errors allowed for the currently specified system were derived from the limits of equipment, not a decision that the errors were the lowest desirable. Flow-compensating equipment available commercially is capable of meeting a ±5 percent error specification at a reasonable cost. The overall proportionality limit of flow-compensated systems should, therefore, remain at the ±5 percent level contained in the proposed rules. However, this level of non-proportionality (±5 percent) may itself be excessive and should be studied further. EMA has stated that they will be submitting data on this issue, which should be useful for this purpose.

Thus, in summary the recommended resolution of this issue is that 1) the proposed flow handling and measurement wording be retained, 2) a provision be added that permits alternate systems if these are shown to yield equivalent results, and 3) a clarification be added which states that the ±5 percent proportionality limit applies to both flow compensated and non-flow compensated systems.

Test Cell Temperatures During Natural Cooldown

Section 86.1334-84 requires the test cell temperature during natural cooldown to be 68 to 86°F.

Summary of Comments: EMA states in their written submission that:

> "...None of the engine manufacturers have the capability of cooling the test cells to assure that the natural cooldown temperature limit can be met. If the limit can

> not be met, then a test may be postponed until the weather changes. This practice is currently inefficient, but it will become intolerable when Selective Enforcement Auditing becomes effective."
>
> "In Section 86.1330-84 the cell ambient temperature during the transient test is not required to be controlled for engines which do not have temperature dependent auxiliary emission control devices. The logic used for the cell ambient temperature during the transient test should also be applied to the natural cooldown."

In an EPA/EMA meeting subsequent to the submission of EMA's comments, this issue was discussed further. One aspect of the discussion centered on the fact that two different temperatures are specified in the Code of Federal Regulations (CFR) at which a cold start emissions test can be started. If the engine is force cooled, it cannot be started unless the oil sump is at 75°F, yet if the engine is naturally cooled it can be started at 86°F. This requirement has been in place since 1984.

Analysis of Comments and Recommendation: The fundamental purpose for cooling an engine by either natural or forced means is to bring it to a temperature that is somewhat representative of an in-use engines cold start. This is particularly important for the measurement of HC and particulate emissions, since emissions of these pollutants tend to decrease as cold start temperatures increase. The temperature specification that was selected for natural cool down was 77°F, with a tolerance range of ±9°F. This was based on the current light-duty practice. Even though the upper limit of this range is 86°F, good engineering practice would dictate a target value for natural cool down of 77°F, and this is in fact the intent of the rule. The fairly wide tolerance band is due to the fact that most test cells due not have precise temperature control, particularly in the summer.

A forced cool down procedure was added at manufacturers' request to shorten the time necessary to prepare an engine for a cold-start test. The upper temperature limit of 75°F for forced cool down is consistent with the natural cool down procedure for two reasons. Since it is relatively easy to control the final temperature of a forced cool down, there is no need to specify a wide tolerance band about the desired target. There is no practical difference between 77°F and 75°F, particularly considering that the forced cool down occurs much quicker than the natural cool down and, thus, some rebound in temperature is likely to occur. Also, since forced cool downs are performed to save time, it is reasonable to expect that they will be stopped as soon as the required temperature is reached. Thus, if 86°F were the upper limit, this would also be the average. The same should not be true for natural cool downs since manufacturers are not expected to purposely control the overnight temperatures of their test cells to the upper-limit 86°F temperature. Thus, unless data are supplied demonstrating that higher cold start temperatures have no effect on emissions, it is recommended that no changes be made in the cool down procedure.

Practically speaking, rejecting EMA's recommendation should only have a minor economic impact on test costs. While air conditioning test cells to ensure temperatures below 86°F for natural cool downs can be quite expensive, this is not the only alternative available to manufacturers. The forced cool down procedure can be used. Some manufacturers objected to this, due to the need to use city water to reach the 75°F limit.. However, internal cooling water can be used to provide most of the necessary cooling and the cooler city water can be used to provide the last 10-20°F of cooling. While constituting some cost, the overall cost is less than that of the water itself, since this water will be added to the cooling water system within the lab and recycled.

Dilution Air Temperature Limits

Sections 86.1310-87(b)(1)(iv)(A) and 86.1310-87(b) 6)(ii)(C) of the proposed regulations provide a temperature specification for primary and secondary dilution of air of 68 to 86°F.

Summary of Comments: EMA provided the following discussion on this issue.

> "The EMA feels that direct control of the primary and secondary dilution air temperatures are not necessary and have a significant cost impact to the manufacturers, especially at this late date. The manufacturers have already committed the large amounts of resources necessary to design and construct the necessary test facilities capable of conducting the transient test procedure for gaseous emissions (finalized in November 1983). The gaseous FTP did not require control of the dilution air temperature and, in light of this, most manufacturers included only heating capabilities into the construction of their testing facilities in order to provide for testing during the winter months. The EMA presented this item in its comments to the EPA on the gaseous FTP in April 1983."

"Due to the leadtime necessary to construct these facilities, in anticipation of the gaseous FTP, the manufacturers were led to believe that the CVS systems constructed to meet these procedures would also suffice for the impending particulate test procedures. To redesign and modify these established systems in order to add the necessary cooling capabilities would be a difficult and expensive task for the manufacturers and could possibly force the relocation of entire CVS systems. An industry estimate ranging from $280,000 to $420,000 has been obtained to equip test cells with the necessary cooling capacity and controls."

The EMA is in support of the 125°F maximum temperature requirement at the particulate filter holder. This temperature limit effectively necessitates primary and secondary dilution air temperatures to be significantly below 125°F. In essence, the particulate filter temperature requirement indirectly regulates the dilution air temperatures to practical ranges. As suggested in SAE Paper 800185,[2] little is known about the influence of dilution air temperature on particulate measurements since investigations to date have not separated the dilution air temperature factor from other dilution and sampling effects. What can be said is that the combined effects of many of these factors on particulate measurements are small, in the range of ambient to 125° F, suggesting that any variations in dilution air temperature would have insignificant effects on particulate measurements."

"The EMA recommends that the dilution air temperature range (68 to 86°F) requirement be modified to allow temperatures above 86°F, provided the dilution air is not artificially heated above this temperature. This would save the manufacturers the cost of adding cooling capacity to their dilution air systems in order to provide for high ambient temperatures occurring during warm summer months."

Analysis of Comments and Recommendations: EMA has suggested that little is known regarding the influence of dilution air temperatures on particulate mass concentrations. While this is partially true, there are some data that show that dilution air temperature is potentially a significant factor. These data are presented by Reichel et al.,[1] where they show a 23 to 33 percent decrease in particulate concentration when the dilution air temperature is increased from 68°F to 122°F. When the dilution air temperature is increased from 86°F to 122°F, the tunnel particulate concentration decreases by about 17 percent. These reductions in particulate concentration are primarily due to the desorption of organics, according to the authors' theoretical calculations and thermogravimetric observations. EMA did not specify how much in excess of 86°F they would like the upper limit for dilution air temperatures and the dilution air temperatures in the manufacturers' facilities would not likely reach the 122°F of the above cited data. Nevertheless, the data do indicate a significant effect on particulate concentration due to dilution air temperatures.

EMA also refers to EPA's promulgation of the final rule for heavy-duty gaseous emissions and they imply that this rule also included all of the provisions needed for particulate measurement. Actually, numerous changes in the final gaseous test procedure requirements were made by EPA so that the manufacturers would not have to invest in equipment needed for particulate measurement at that time, if not so desired. EPA's intent in so doing was to delay particulate testing equipment requirements such that there could be a more ordered phase-in for these equipment needs. One way of doing this was to attempt to assure that new equipment that would be purchased for compliance with the gaseous emissions testing rules would also be useful when particulate testing was required. For example, use of a dilution tunnel was allowed under the gaseous emission regulations, but was not required. However, the gaseous rules and supporting documents did not imply that particulate testing would not require additional equipment and specifications such as secondary dilution tunnels, weighing balances, and dilution air temperatures. An additional observation on dilution air temperature limits is that these limits have also been in effect for seven years of light-duty particulate testing.

Therefore, since dilution air temperatures can have a substantial effect on particulate emissions, no changes in the proposed dilution air temperature requirements should be made until some further date when sufficient data are available to establish that no effect is present or to establish satisfactory correction factors.

Humidity Effect Correction Factor for Particulate Measurements

No humidity-related correction factor currently exists for particulate measurement.

Summary of Comments: EMA submitted a limited amount of data on the effects of humidity on particulate measurements and intends to submit additional engine data at a later date. The current set of data show that the effect of humidity on particulate is in the opposite direction and about three-fourths the size of that for NOx. The equation would be of the same general form as the NOx humidity correction factor equation.

EMA recommends that EPA consider a humidity effect correction factor for particulate measurements using the submitted data, with the option of accepting additional data at a later date.

Analysis of Comments and Recommendation: The data that are available on this subject are very limited (see Table A-2) and are an inadequate base upon which to formulate a rule change of the magnitude suggested in the EMA comment. In particular, no data exist on the impact of various control technologies (e.g., trap-oxidizers) on this effect. Therefore, it is recommended that resolution of this issue await receipt of additional data.

Sulfur Correction Factor

EMA suggests that a sulfur correction factor similar to the NOx humidity correction factor be employed to correct for the observed increase in particulate with an increase in fuel sulfur.

Summary of Comments: EMA cites data that show that for each 0.05 percent fuel sulfur mass increase, there is a corresponding increase in measured particulate emissions of 0.024 g/BHP-hr due only to the change in fuel sulfur. EMA suggests that a correction factor be used to correct for this perceived inequity. Furthermore, EMA believes that a sulfur correction factor will become more important as particulate standards become more stringent in the future.

Caterpillar raised a similar concern about the inclusion of water (which is associated with sulfate particles) in measured particulate mass.

Analysis of Comments and Recommendation: Recent test data have been generated in two apparently well-designed and controlled studies to determine the effects of various diesel fuel parameters on particulate emissions. Sulfur content was one of the parameters studied and a significant effect was found. EMA quotes the results of one of these studies; that conducted by Chevron. (Data from the other study by Mobil and Caterpillar have not yet been published.) Thus, the fact that fuel sulfur content affects particulate emissions is an accepted phenomena. However, how this effect varies from engine to engine and with control technology is not well known.

EPA's current test fuel specification for sulfur levels is between 0.2 and 0.5 weight percent. However, EPA's intent is to use a fuel that is representative of commercial fuel and closely specifies sulfur content when purchasing test fuel. This approach limits changes in EPA's fuel sulfur levels to

Table A-2

Calculated "A" Values For Particulate Humidity Correction Factor

Engine	Calculated "A"*	Mean Part. (g/BHP-hr)
Cummins #1	+.0022	.66
Cummins #2	+.0022	.38
Mack #1	+.00144	.56
Mack #2	+.00099	.38
Mack #3	+.00042	.45
Mack #4	+.00017	.83
Mack #5	+.00255	.50
Mack #6	+.00123	.49
Mack #7	+.00275	.42
Mack #8	+.00138	.35
Mack #9	+.00107	.61
Mack 676	+.00317	.64
IHC #1	+.00107	.61
Cummins 903	+.00383	.79
DDAD 871	+.00303	.42
Caterpillar #1	+.00204	.67
Caterpillar #2	+.00205	.52
Caterpillar #3	+.00094	.40
Caterpillar #4	+.00107	.52
Caterpillar #5	+.00113	1.77
Caterpillar #6	+.00097	.56
Avg.	0.00170	

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* Equation for Correction Factor:

$$\text{Corrected Particulate} = \left(\frac{1}{1 + A\,(\text{Humidity} - 75)}\right) \times \text{Observed Particulate}$$

±0.05 weight percent sulfur or less. Taking Chevron's relationship at face value, this change in sulfur levels could result in a change in particulate emission levels of ±0.024 g/BHP-hr, which is ±4 percent of the 0.6 g/BHP-hr particulate standard. While this effect would represent a greater percent of a 0.25 g/BHP-hr particulate standard, use of particulate control devices such as traps should reduce the size of the fuel sulfur effect somewhat. Nevertheless, this degree of potential variability is larger than generally desired.

The relatively wide specification for sulfur content allows the sulfur content of the test fuel to change with that of commercial fuel without requiring modifications to the CFR, which are costly and time consuming. This flexibility is intended, from EPA's point of view, and should be maintained. Use of a sulfur correction factor would necessarily require that a target fuel sulfur level be specified, essentially removing this flexibility. As the sulfur content of EPA's current (or projected future) test fuel is not markedly different that that used to develop all of the particulate emission data used in the technical feasibility analysis in Chapter 2, retention of the current provisions does not affect the feasibility of the standards being promulgated as long as the sulfur levels of commercial fuels do not increase dramatically in the future.

The issue of in-use sulfur levels is addressed in Chapter 2, as a number of manufacturers requested that in-use sulfur levels be controlled to lower levels by EPA to allow use of various aftertreatment technology. There it was determined that the feasibility of the final particulate standards was not contingent upon this control. However, it was also indicated that the control of commercial fuel sulfur content would be further investigated in the future as a means of controlling particulate emissions. Investigation of the potential for in-use sulfur levels increasing in the future is a natural part of such a study. Thus, any potential for high in-use sulfur levels, and thus, high certification fuel sulfur levels, to cause the particulate standards to be infeasible will be investigated at that time. In the meantime, with relatively constant fuel sulfur levels, feasibility should not be an issue. Thus, it is recommended that no changes be made to the test procedures to account for the sulfur content of the test fuel.

Caterpillar suggested the elimination of the inclusion of water associated with sulfate in the measured particulate mass. How this could be done is not clear at this point and requires further study. However, ammoniation of the filtered particulate is one possible approach. As discussed above, the standards being promulgated are based on measurements which include such water. Removing the water now would either reduce the stringency of the standards or require that the standards be modified. Thus, no action should be taken with respect to water measurement at this time. Further study may be merited, however, if future sulfur levels increase, or if desirable future control technology is found to affect sulfate, and thus, water levels. This study should be coupled with the analysis of future commercial fuel sulfur levels and their potential control described above.

III. Issues Raised by EPA in NPRM

The NPRM requested comment on four issues because of potential improvements were believed to exist in these areas. These areas were: 1) the possibility of relaxing the cycle performance statistics of horsepower standard error, 2) the possibility of changing the primary torque measurement method to an electronically compensated case load system, 3) the NOx correction factor for humidity, focusing on the adequacy of the current factor for low NOx engines and 4) the addition of a standard calibration procedure for HDGE throttle control systems.

In general, EPA received little response to these issues. From the comments that were received it can be concluded that there is no dissatisfaction or known problems with the current system. The only area that did result in the receipt of data was the NOx correction factor, where the data presented indicated that the current NOx correction factor was appropriate for low NOx engines as well as current engines (see Tables A-3 and A-4). Thus, as a result of the comments and analysis of these four issues, no changes should be made in these areas.

IV. Other Issues

The last group of issues do not directly relate to Subpart N but will nevertheless be addressed here because they deal with test procedures.

Smoke Standards

EPA did not propose to eliminate the current smoke standards when it proposed to add particulate standards.

Summary of Comments: Mack commented that an engine that meets the 0.60 g/BHP-hr standard will easily pass the smoke standards and therefore, the smoke standards are not needed. They present no data to support this but state that it is based on limited data.

Table A-3

Calculated "A" Values For NOx Humidity Correction Factor -- Engines With NOx Emissions Greater than 6.0 g/BHP-hr

Engine	Mean NOx (g/BHP-hr)	Calculated "A"*
Previously Submitted Data**		
Caterpillar #1	6.68	-.0017
Caterpillar #2	8.96	-.0025
Cummins #2	7.66	-.0023
Cummins #3	6.36	-.0017
Mack #1	7.85	-.0032
Mack #2	9.39	-+.0028
Mack #3		-.0028
Mack #4	7.74	-.0037
Mack #5	7.44	-.0025
Mack #6	7.02	-.0024
DDAD #3	6.12	-.0029
Mack 676	7.47	-.0022
DDAD 871	7.66	-.0025
Additional Data		
Caterpillar #1	9.11	-.0027
Caterpillar #2	7.98	-.0029
	Average A =	-.00259

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* Equation for Correction Factor:

$$\text{Corrected Particulate} = \left(\frac{1}{1 + A\,(\text{Humidity} - 75)}\right) \text{X Observed Particulate}$$

** Public Docket No. A-80-18, Particulate Regulations for H.D.D.E., "Statement of the EMA." September 13, 1982, Appendix "D", p. 2, Table 1.

Table A-4

Calculated "A" Values For NOx Humidity Correction Factor -- Engines With NOx Emissions Less than 6.0 g/BHP-hr

Engine	Mean NOx (g/BHP-hr)	Calculated "A"*
Previously Submitted Data**		
Cummins #1	5.41	-.0021
Mack #1	4.93	-.0024
Mack #2	5.73	-.0029
Mack #3	5.40	-.0029
Mack #4	4.97	-.0027
Mack #5	4.53	-.0025
Mack #6	4.46	-.0028
DDAD #1	4.74	-.0032
DDAD #2	4.05	-.0036
Cummins 903	5.05	-.0023
Additional Data		
Caterpillar #3	5.96	-.0021
Caterpillar #4	5.16	-.0024
Caterpillar #5	4.82	-.0027
Caterpillar #6	4.61	-.0026
	Average A =	-.00266

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* Equation for Correction Factor:

$$\text{Corrected Particulate} = \left(\frac{1}{1 + A\,(\text{Humidity} - 75)}\right) \times \text{Observed Particulate}$$

** Public Docket No. A-80-18, Particulate Regulations for H.D.D.E., "Statement of the EMA." September 13, 1982, Appendix "D", p. 2, Table 1.

Analysis of Comments and Recommendation: Low particulate emission standards may lower smoke levels on average, but will not necessarily guarantee smoke levels below the smoke standard. This is because the two standards and their associated test procedures are not mutually inclusive as to intent and result. The purpose of the smoke standard is to control worst-case smoke levels, whereas the purpose of the particulate standards is to control average transient cycle particulate. Since the engine operating conditions which produce worst-case smoke are not dominant in the transient cycle, a given engine could conceivably pass the particulate standard and fail the smoke standard. The implementation of traps may be the one particulate control approach that would provide smoke control, since traps are effective under all driving conditions. However, it is unlikely that all future engines will be equipped with traps and the cost of running a smoke test is quite small. Thus, it is recommended that the smoke standards and their associated test requirements be retained.

Official Test Data

Paragraph 86.090-29(b)(3)(i) requires that the Administrator's data shall comprise the official test data for any engine tested.

Summary of Comments: Mack feels that there is a wide variation in test results from facility to facility with no one facility singled out as grossly superior or in error. Accordingly, in cases where the manufacturer and Administrator differ by more than 10 percent, Mack recommends use of a third laboratory as a referee.

Analysis of Comments and Recommendation: The designation of EPA data as the official test data has been in effect since the implementation of emission standard in the early 1970's. As no evidence was presented that demonstrates why the current approach is inadequate, it is recommended that no change should be made.

EPA Approved Equipment

Paragraph 86.090-29(b)(2) requires the manufacturer to provide "...instrumentation and equipment specified by the Administrator...." (underlining added).

Summary of Comments: Mack commented that "In the past, manufacturers have been allowed deviations from the instrumentation specified in the Code of Federal Regulations based on demonstrated equivalency. Mack feels that there is no reason to abolish this practice and the flexibility that it allows. They feel that demonstrating equivalency guarantees that the accuracy of the testing will not suffer. Mack feels that the wording should be changed to "...instrumentation and equipment approved by the Administrator..." to allow the manufacturer the flexibility to install the instrumentation and equipment in a manner most suitable to his operation.

Analysis of Comments and Recommendation: The requirement for equipment specified by the EPA has been in place for many years. This requirement provides EPA with the flexibility of being able to specify use of a particular measurement procedure or technique to enable a more confident assessment of the emissions of an engine. Whereas this flexibility should be retained, it should be pointed out that EPA has no intention of being unreasonable in exercising this provision. To date, EPA has rarely, if ever, exercised this authority to require use of special equipment with respect to heavy-duty diesel testing. Therefore, it is recommended that this provision be retained in its current form.

References

1. "Influence on Particulates in Diluted Diesel Engine Exhaust Gas," Stefon Reichel, Franz Pischinger, Gerhard Lepperhoff, SAE Paper 831333, 1983.

2. "Experimental Measurements of the Independent Effects of Dilution Ratio and Filter Temperature on Diesel Exhaust Particulate Samples," J. S. MacDonald, S. L. Plee, J. B. D'Arcy, and R. M. Schreck, SAE Paper 800185, Detroit, February 1980.

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